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CONSTRUCTION OF AN UNATTENDED SEISMO-
LOGICAL OBSERVATORY (USO) IN PERMAFROST

G. Robert Lange

Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire

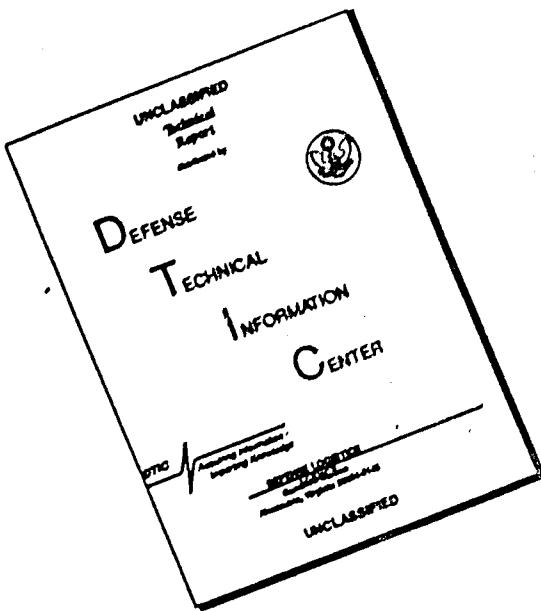
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CONSTRUCTION OF AN UNATTENDED
SEISMOLOGICAL OBSERVATORY
(USO) IN PERMAFROST

G. Robert Lange

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The construction of a large diameter cased borehole and surface instrument shelter for the installation of a high resolution, long term recording seismograph in marginal permafrost 15 miles west of Fairbanks, Alaska, is described. Permafrost extended to a depth of 123 ft and consisted of frozen silt, peat and sandy small gravel and was underlain by a thawed gravel aquifer. The first 48 ft of 16-in. hole was drilled with a truck-mounted auger. A Failing 1500 mounted on a tracked trailer was modified to accommodate a 4-in.-ID kelly, swivel and drill pipe so that compressed air in reverse circulation could be used for cuttings removal. Air was circulated by either pressurizing the annulus through a rotating seal or by an air eductor (injector). These systems were used to complete the hole to 92 ft. Although considerable difficulty was encountered, drilling rates of 10 ft/hr were measured when using compressed air chilled to below 20°F, shrouded bits to provide adequate bottom hole cleaning and either the eductor or the pressurized annulus. The latter is preferred since compressed air requirements are much less. Eleven and three quarter in. O.D. casing with flush, step-threaded joints was set using a soil-water-snow slurry as grout. Forty thermocouples were installed in the fill placed over the casing and in the ground beneath to monitor thermal behavior. Data from these are discussed. Five thermistors attached to the borehole package yielded data on the ground temperature at the 80 to 85-ft depth interval. Using these data, the permafrost thickness obtained by exploratory drilling, and the mean annual air temperature, the ground temperature profile at depth is estimated. This analysis		

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Drilling Drilling rigs Permafrost Seismological stations						

13. Abstract (Cont'd)

yields a ground temperature of about -1.7°C for a depth of fifty feet (minimum depth of zero annual amplitude). It is concluded that rapid construction of similar installations in permafrost regions is feasible, but would present formidable logistical problems. Drilling "big holes with little rigs" in almost any frozen soil or rock also appears feasible. However, considerable development work will be required on this and other aspects of the problem before 100% success can be guaranteed for each hole started, considering the original limitations arbitrarily set on the problem; i.e., construction in unfriendly countries, in one week's time, with air transportable equipment.

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PREFACE

This report was prepared by Mr. G. Robert Lange, Geologist, Northern Engineering Research Branch (Mr. William F. Quinn, Chief), Experimental Engineering Division (Mr. Kenneth A. Linell, Chief), U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL). Mr. Lange also served as project leader for USA CRREL during field construction.

The work described in the report was performed for the Sandia Corporation by USA CRREL under US AFC order number AL-66-413, dated 9 December 1965, change order no. 1 issued 21 March 1966, and change order no. 2 issued 1 July 1966. An additional AFC order, AL-67-28, was issued 1 July 1966.

SP 4 Charles L. Howard, Engineering Geologist, USA CRREL, served as assistant project leader for USA CRREL in the field, and assisted with data reduction. Mr. Paul V. Sellmann, USA CRREL, assisted with the site examination and drafted that portion of this report. He also furnished the data regarding the properties of the frozen peat. The entire staff of the USA CRREL Alaska Field Station provided field support and Messrs. Jack Tedrow and Dan Dinwoodie were especially helpful. SP 5 Larry Elliott, SP 4 Gerald Coleman, Pvt John Simmons and Pvt Robert Bishop of the Research Support Group, Ft. Belvoir, served as drill crew. Mr. William Quinn was responsible for the design thermal analysis. Mr. Richard Berg, USA CRREL, reduced the temperature data from the fill, prepared the isothermal diagrams and assisted in the interpretation of those data. The following USA CRREL staff members assisted in the preparation of the engineering study: Messrs. Frederick Crory, Edward Lobacz, William Quinn and Frederick Sanger.

The encouragement and support of the following USA CRREL supervisory personnel were instrumental in assuring the success of the project: Mr. Albert F. Wuori, Chief, Applied Research Branch, Mr. Kenneth A. Linell, Chief, Experimental Engineering Division, who served as contact at USA CRREL for Sandia Corporation, and Mr. W. Keith Boyd, then Technical Director, USA CRREL. The following USA CRREL staff members critically reviewed drafts of this report and made many valuable suggestions: Messrs. Paul Sellmann, Frederick Sanger, Albert Wuori, Charles Howard and Edward Lobacz. Mr. Ronald Atkins and others of the Technical Services Division, USA CRREL, constructed and calibrated the thermocouple and thermistor cables with speed and accuracy.

The assistance of military personnel during the flood emergency has been acknowledged in a letter from Commanding Officer, USA CRREL, to Commanding Officer, Ft. Wainwright, copy to Sandia Corp.

The following individuals from Fairbanks furnished valuable information that was of assistance in site selection: Dr. Edward Berg, Seismologist, Geophysical Institute, University of Alaska, Mrs. Florence Weber, Geologist, U.S. Geological Survey, University of Alaska, Mr. J. Lowery, State Division of Lands, Fairbanks, Messrs. W. Glavinovich and N.D. Eagan, U.S. Smelting, Mining and Refining Company, Fairbanks, Mr. Maurice Butler, driller, Fairbanks.

The author also wishes to express his appreciation for the cheerful spirit of cooperation demonstrated by all of the Sandia personnel connected with the project.

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CONSTRUCTION OF AN UNATTENDED SEISMOLOGICAL OBSERVATORY IN PERMAFROST

by

G. Robert Lange

INTRODUCTION

The original objectives of this entire project were as follows:

1. Sandia Corporation was to demonstrate the feasibility of recording seismic events over 120-day periods with an unattended borehole seismometer and recording equipment.
2. USA CRREL was to demonstrate the feasibility of rapidly constructing the cased borehole and adding surface fill in remote arctic locations where permafrost might or might not be encountered.

The restrictions that were expected to be imposed on remote construction were:

1. Site selection, drilling, surface construction and seismometer installation were to be accomplished in one week.
2. The hole was to have a maximum depth of 200 ft and be large enough in diameter to accommodate 11-in.-ID casing.
3. Only air-transportable equipment, with single pieces weighing less than 20,000 lb, was to be used.
4. The location was to have a low level of seismic background noise.
5. Drilling equipment was to be able to attain a rapid overall rate of penetration in any material, including all types of frozen and unfrozen rock and soils.
6. Surface installation was to be tamper-proof, or at least tamper-resistant.
7. Temperature range in the instrument shelter was to be -40°F to +135°F.

All these restrictions were not imposed on the prototype since construction had to be complete before thawing of the ground surface in the spring.

Since one of the most difficult aspects of the problem was the development of a highly effective, lightweight drilling system for holes of from 12 to 16 in. diam, emphasis was to be placed on its development. However, it became obvious during construction that the total effort would have to be directed towards completing the installation before the ground began to thaw. Systematic trials of the "big hole, little rig" equipment, core sampling, and geothermometry at the site were to be delayed until the fall of 1966.

SITE EXAMINATION

Personnel from Sandia and USA CRREL began site examination for the Unattended Seismological Observatory on 7 March 1966. Criteria for the selection of a site involved local geology, seismology and environment. The original criteria stated that the site should:

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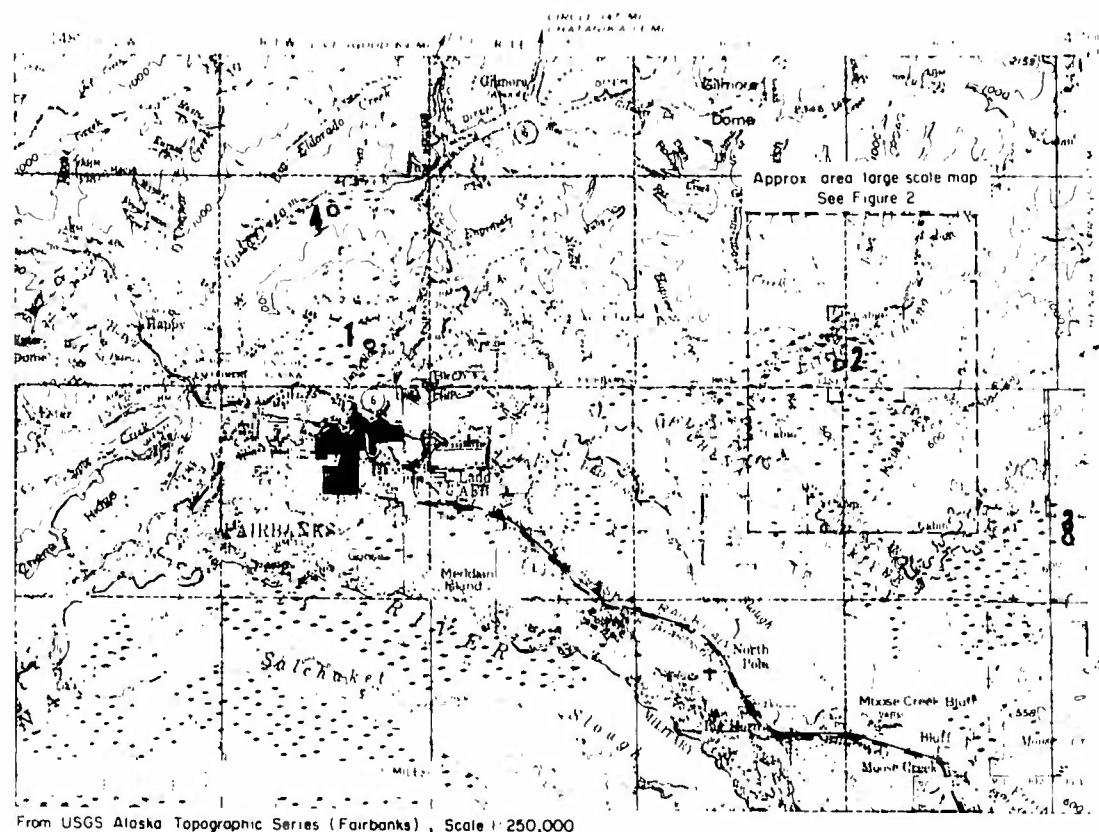


Figure 1. Site location map. 1) Alaska Field Station, 2) Chena Hot Springs Road, 3) Eielson AFB, 4) Goldstream.

1. Be underlain by a minimum of 80 ft, but preferably as much as 200 ft, of fine-grained perennially frozen material.
2. Be seismically quiet: at least 1 mile from roads and 3 miles from railroads, and in minimal tree cover to reduce wind-generated seismic noise.
3. Have sufficient relief to provide adequate surface drainage.
4. Be located on easily obtainable land.

Initially it was hoped that a site could be selected that was underlain by as much as 200 ft of perennially frozen silt (the maximum to be expected in the area). It was assumed that frozen silt would be easier to drill than ice-indurated gravel. In the Fairbanks area the criteria were met only in the fine-grained material in Pleistocene valley sections. Land is easy to obtain in these low-lying areas because it is undesirable for agricultural, residential or industrial use. Unfortunately these sites have a high cultural seismic noise level. The Fairbanks area is surrounded by a transportation network that is unique for a remote northern location. The network includes railroads and heavily traveled improved highways as well as trails that are used seasonally by all types of off-road vehicles. Agricultural, construction and mining operations are also sources of seismic noise. A number of sites that had the proper geological setting were not considered because of the probability of an intolerable seismic background noise level from cultural activities.

Sil: Deposits 200 ft thick are not common in the valleys of the Yukon-Tanana Uplands, the rolling land adjacent to and just north of Fairbanks (Fig. 1). The few areas where accumulations exceed 100 ft in thickness were eliminated because of seismic noise. Therefore, the first sites selected were immediately south of the southern boundary of the Yukon-Tanana Uplands where it was hoped that

thick alluvial sections of frozen fine-grained material would be available. A description of the sites examined (Fig. 1) and a discussion of their relative merits follows.

Alaska Field Station site. This site was on land which could be easily withdrawn from public use 0.75 mile west of the USA CRREL Alaska Field Station in the low marshy area enclosed by the Farmer's Loop Road (Fig. 1). The site was of interest because previous drill hole logs in the area showed that up to 200 ft of frozen fine-grained material was available. This is probably the maximum known thickness of permafrost in the Fairbanks district. Seismic background monitoring was performed by Sandia personnel using a surface geophone. A high background noise level, based on experience in the southern 48 states, was recorded although the level was still permissible. Coupling between the Field Station and the geophone site was checked by dropping a 1-ton pile driving hammer free fall about 5 ft to the ground at the Field Station. The 10,000 ft-lb signal was easily detectable at the geophone site except during one period of relatively high wind velocity.

Advantages of the site:

1. It had thick deposits of frozen fine-grained material.
2. It was near and easily accessible from USA CRREL Field Station facilities and other shop and equipment centers in Fairbanks.

Disadvantages of the site:

1. It had a high, although permissible, seismic noise level.
2. There was the possibility of a higher noise level during the summer months caused by agricultural activity within $\frac{1}{2}$ mile of the site.

Chena Hot Springs Road site. This site (Fig. 1, 2, 3) was on a floodplain of the Little Chena River south of the silt-mantled Yukon Tanana Uplands, approximately 13 miles from the Steese Highway on the new Chena Hot Springs Road. Since the Little Chena drainage heads in the silt-covered uplands it was hoped that the resulting alluvial deposits would consist primarily of fine-grained material.

Advantages of the site:

1. It was seismically quieter than any other site monitored.
2. It was close enough to a major road for relatively easy winter accessibility.
3. It was located on public land which could be easily withdrawn from use.

Disadvantages of the site:

1. After exploratory drilling it was found that the perennially frozen section was not entirely made up of silt; it graded from silts near the surface to sands and small gravel with depth. The depth of perennially frozen ground was approximately 122 ft (see next section). However, this subsurface information was not available until after the Sandia seismic crew left Fairbanks and initial site examination was complete.
2. The site was in a low-lying area that might have been subject to minor flooding during spring runoff.

Eielson AFB site. The third site was near the northern limit of Eielson AFB (Military Reservation, Fig. 1). The cultural and natural seismic noise levels were low but the site was found to be near a tank maneuver area and was therefore rejected.

Goldstream site. Following rejection of the Eielson AFB site it was necessary for the Sandia Corporation seismic crew to return to Albuquerque to complete preparation of the down-hole instrument package. With the Eielson site eliminated, only two sites remained where seismic background noise levels had been determined. To guard against the possibility of both the monitored sites proving

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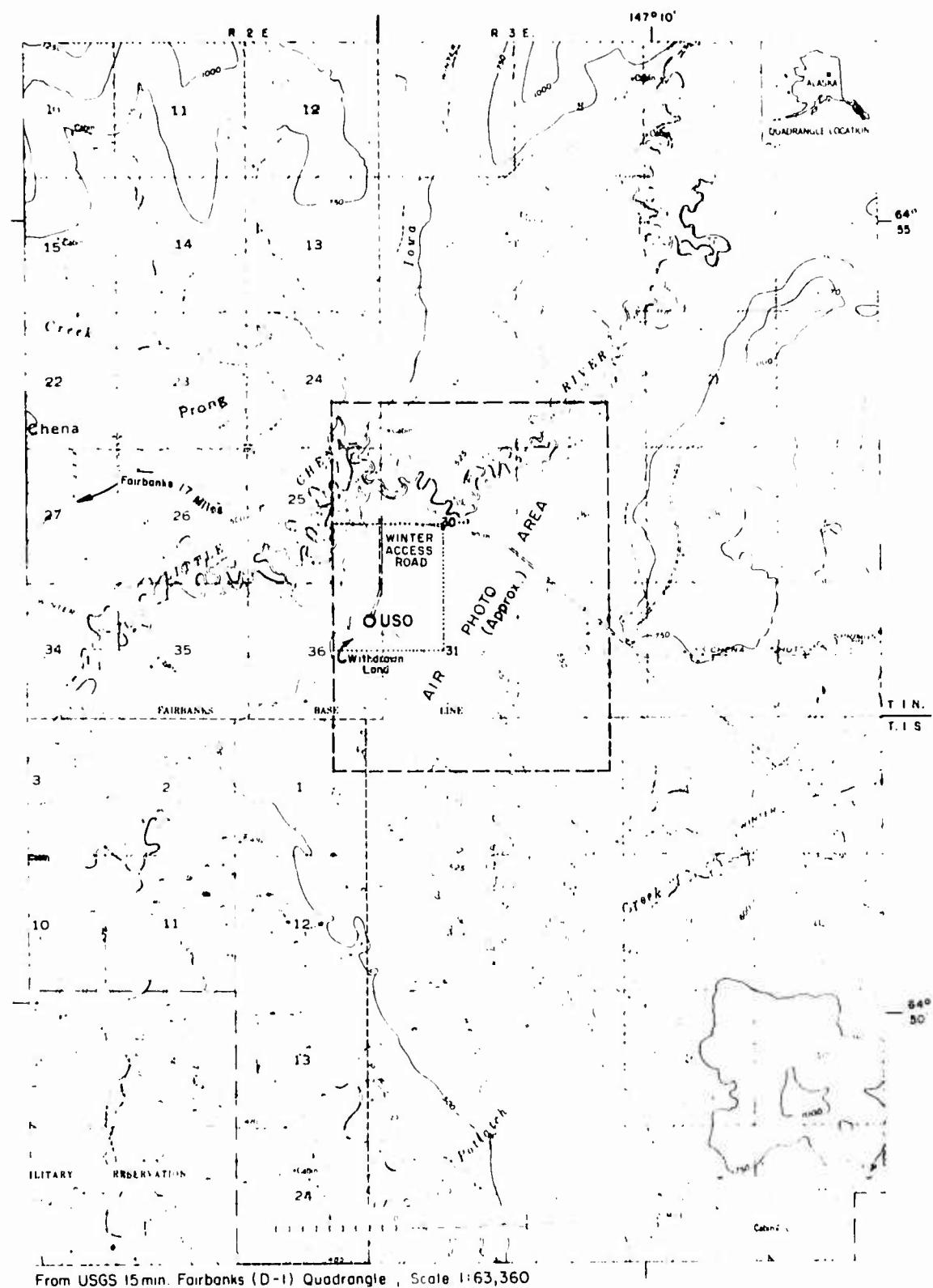


Figure 2. Large scale map of Chena Hot Springs Road site (Section 36, T. 1 N., R. 2 E.).

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Scale ~ 1:18 000
Figure 3. Air photo of Chena Hot Springs Road site.

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unsatisfactory, an additional site was considered. It was located about 4 miles west of the Steese Highway on the southern margin of the Goldstream Valley (Fig. 1).

Advantages of the site

1. It had adequate relief to provide good year-round surface drainage.
2. Frozen silt 130 ft thick was indicated by a hole drilled and logged in the area by U.S. Smelting, Mining and Refining Company.
3. Since the site was on the north-facing side of the valley, a thin active layer could be expected, thus improving summer trafficability.
4. Even though the site had not been monitored, it was expected to be seismically quiet since it exceeded all the required distances from cultural activity.

Disadvantages of the site

1. Trees were too high in adjacent areas (although tree cover was so sparse the site could have been cleared easily).
2. A long access road was required.

Before the exploratory drilling described below, it appeared that the order of desirability of the sites would be

1. Goldstream site (assuming it to be seismically quiet).
2. USA CRREL Alaska Field Station site.
3. Chena Hot Springs Road site.

It was unfortunate that it was necessary to rely upon seismic background noise levels obtained in winter when those during the high cultural activity periods of summer are often much higher. Some speculation was made on how the activity level would change seasonally at all of the sites.

EXPLORATORY DRILLING AND SITE SELECTION



Figure 4. Exploratory drilling, Chena Hot Springs Road site.

Based chiefly upon seismic observations, the Chena Hot Springs Road site was selected as the first to be explored by drilling. Surface site examination and evaluation were completed 14 March and preparations for exploratory drilling were begun 15 March. A winter road was bulldozed through about 1 mile of sparse timber from the Chena Hot Springs Road to the site.

The truck-mounted Failing 13 rotary drill and air compressor were mobilized on the site 16 March (Fig. 4) but drilling was not begun until 18 March due to difficulties in starting the compressor. In the interest of speed, drilling was done with 5-in. dia. and roller-cone rock bits rather than tv cores. Six hundred ft³ min of compressed air was supplied by an air-fired air heat exchanger and used as the drilling fluid. The cuttings were examined and a log was recorded (Fig. 5). From the surface to 7.5 ft, the material consisted of frozen peat; at 7.5 ft, frozen silt was encountered with infrequent thin layers of frozen gravel and peat. The section from 35 to 53 ft consisted of many layers of

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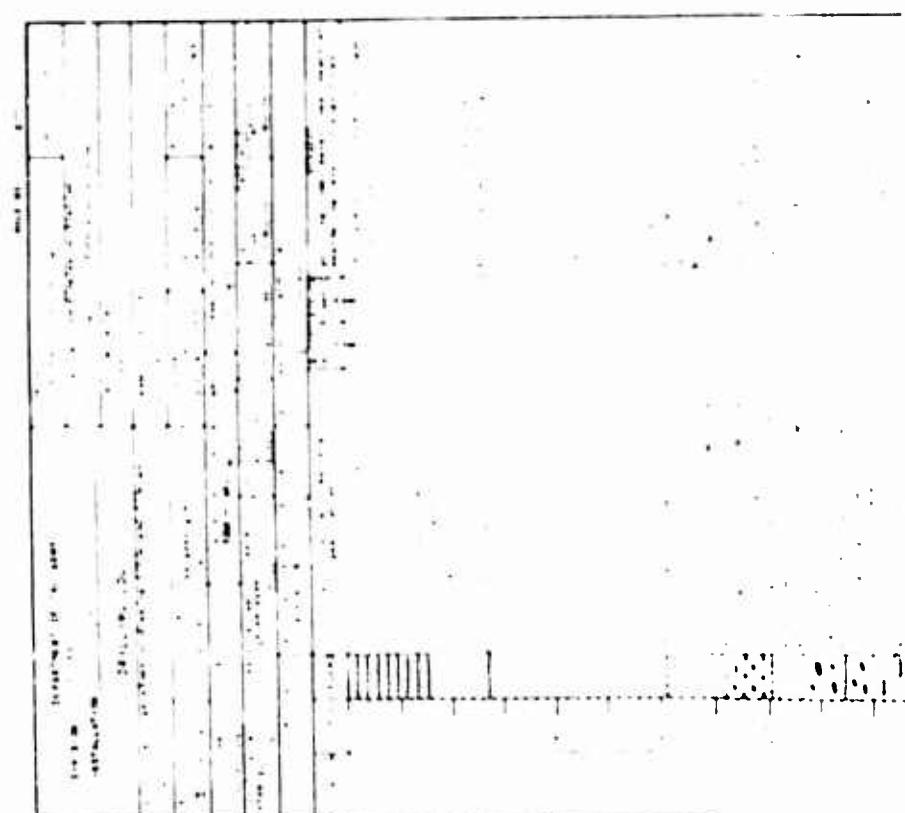
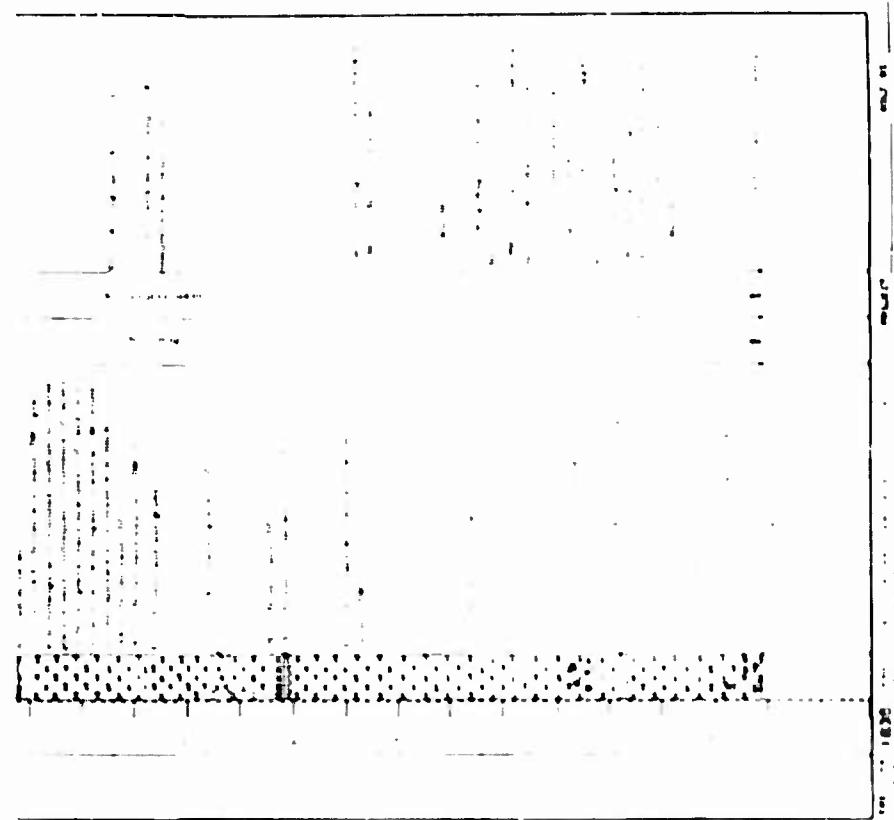


Figure 5. Drilling log.

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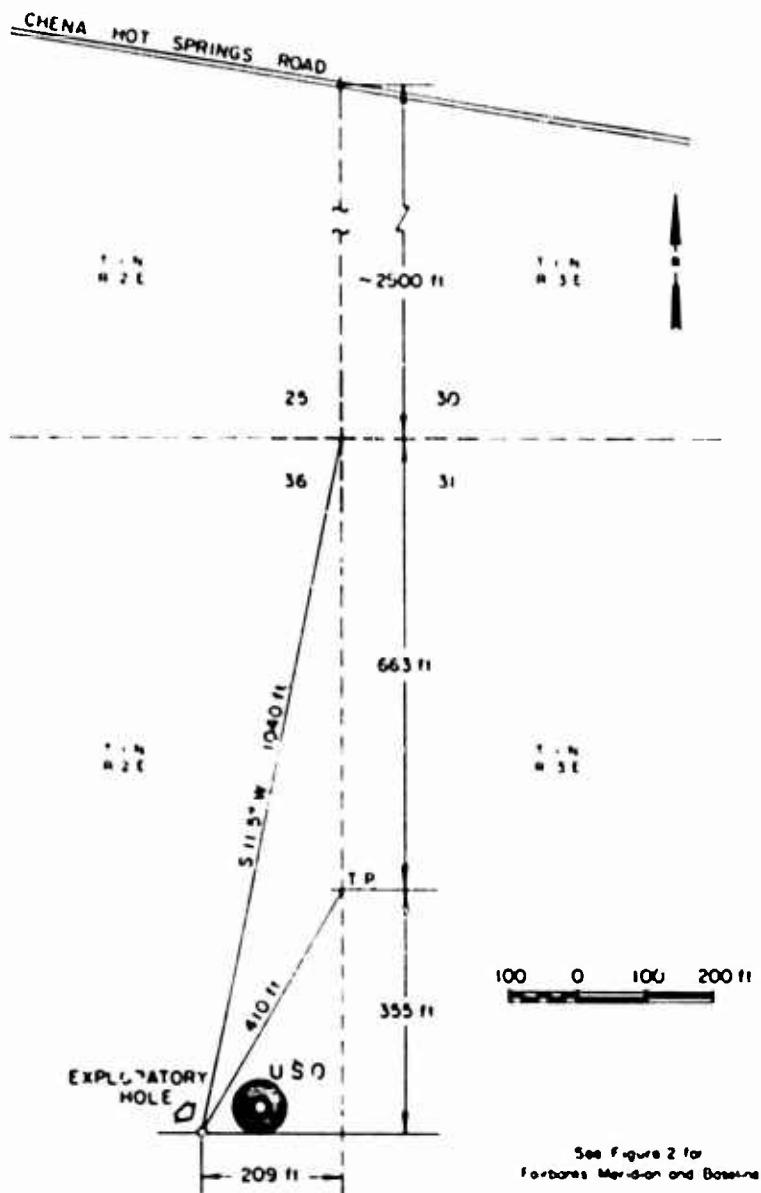


Figure 6. Location of USO and exploratory hole.

frozen peat, silt, sand and sandy gravel ranging in thickness from an inch or two to several feet. From ~ ft to the bottom of permafrost (122-124 ft) frozen silty sand with layers of frozen sandy gravel and frozen silt were encountered. The gravel content increased sharply in the final few feet. It was impossible to determine the bottom of permafrost with more accuracy than + 1 ft due to the abrupt influx of groundwater that occurred when permafrost was exited. The water rose to within 15 ft of the ground surface and was frozen a few days later. This prevented observation of equilibrium ground temperatures in the hole, however, it was expected that an additional hole could be cored at the site in the fall of 1966 and that a ground temperature profile could be obtained at that time.

The exploratory drill hole was completed 22 March. Based on information from this hole final selection of the Chena Hot Springs Road site was made on 25 March. Four quarter sections of land* surrounding the site were withdrawn from public use (see Fig. 2, 6).

*NE quarter sect. 36 T. 1N, R. 2E (contains site)
SE quarter sect. 25 T. 1N, R. 2E

SW quarter sect. 30 T. 1N, R. 3E
NW quarter sect. 31 T. 1N, R. 3E
Fairbanks Meridian, Fairbanks Base Line



Figure 7. Rigging up modified Failing 1500 at Alaska Field Station. Note special hex kelly, Chiksan joint, pull down web and chains.

PREPARATIONS FOR "BIG HOLE" DRILLING

Haulage of 500 yd³ of gravel for surface fill and road ramp began on 30 March. Ten-yard-capacity gravel trucks with dual tandem rear axles (gross vehicle weight approximately 25 tons) made about 40 trips over the still-frozen surface with little difficulty and no damage to the winter road.

The Failing 1500 rotary drill was disassembled for modification for "big hole" drilling (Fig. 7). The "big hole" parts and casing arrived from Albuquerque via a C-54 aircraft on 1 April. Modification for reverse circulation was effected by replacing the 1 $\frac{1}{2}$ -in.-ID kelly, chuck and regular hex drive quill with a kelly having a hexagonal surface outside and a 3-in. round ID. Further the 1 $\frac{1}{2}$ -in.-ID drilling swivel was replaced by a 4-in.-ID "Chiksan" joint* which weighed and cost far less than a conventional drilling swivel. Because it was necessary to remove the regular chuck, which is normally used to transmit rig weight from the hydraulic cylinders to the kelly, an alternate method of weight transfer was necessary to mobilize all dead weight available to the 14-16-in. bits. This was accomplished by the arrangement illustrated in Figures 8 and 9 and described below. Three 1 $\frac{1}{2}$ -in. plates were welded as webs to the Chiksan joint and a hole was drilled in each web. The hole in the upper web, which was aligned longitudinally, was used to attach the Chiksan swivel joint to the main hoist line in order to raise and lower the drill string. The two laterally oriented webs were

*A fluid handling swivel pipe joint with sealed bearing for fluid handling applications.

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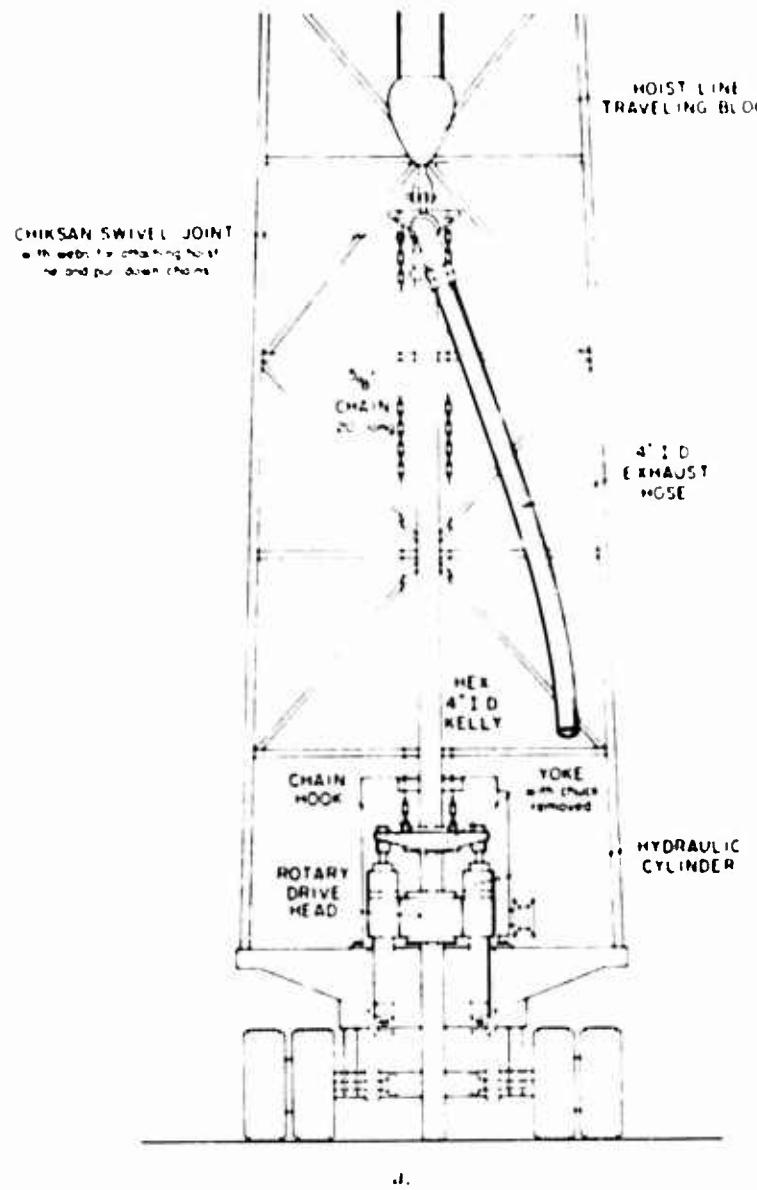


Figure 8. Existing 1500 trailer mounted drill rig with modifications for drilling large diameter holes.

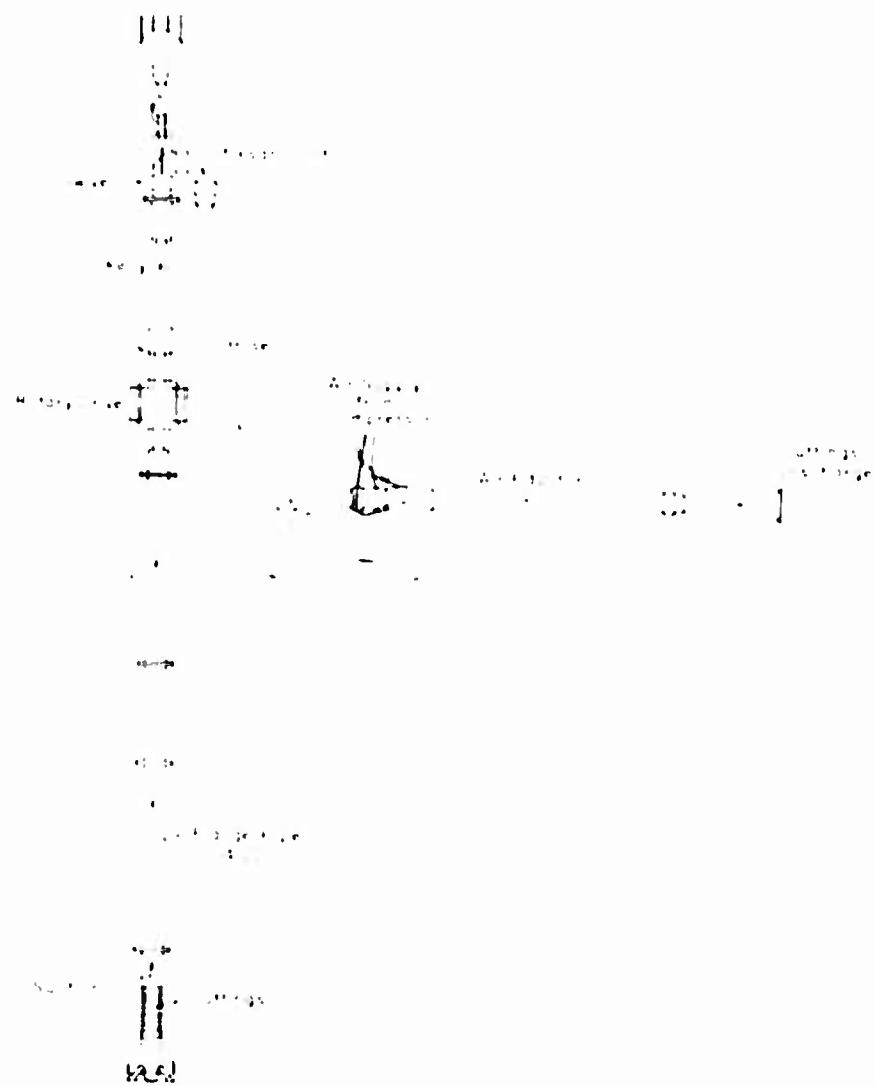
attached to 1/2-in. chains which in turn were attached to the top of the hydraulic feed yoke. Thus, the hydraulic feed system was available to apply part of the weight of the rig to the bit.

Two schemes for drilling "big hole" with reversed circulation of compressed air were proposed in the engineering study. Using the pressurized annulus method compressed air flowed down the annulus to the bit where cuttings were picked up. The cuttings were then carried up the inside of the 4-in.-ID drill pipe and kelly, around the swivel and discharged through an exhaust hose.

We also proposed to experiment with the use of an air injector, or eductor, on the exhaust end of the same circulation system described above. Negative pressure is created in a mixing chamber behind carefully designed ultrasonic nozzles which are supplied with 1200 ft³/min of primary air at 100 psig (see Fig. 8b, 8c).*

*The eductors were designed by Prof. Robert C. Dean, Creare Inc., Hanover, N.H. and described in their report to CRREL: Creare Report N-58, *Drill Hole Cleaning Ejector*.

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b. Air eductor for reverse circulation rotary drilling.



c. Reverse circulation of air-eductor scheme.

Figure 8 (Cont'd).

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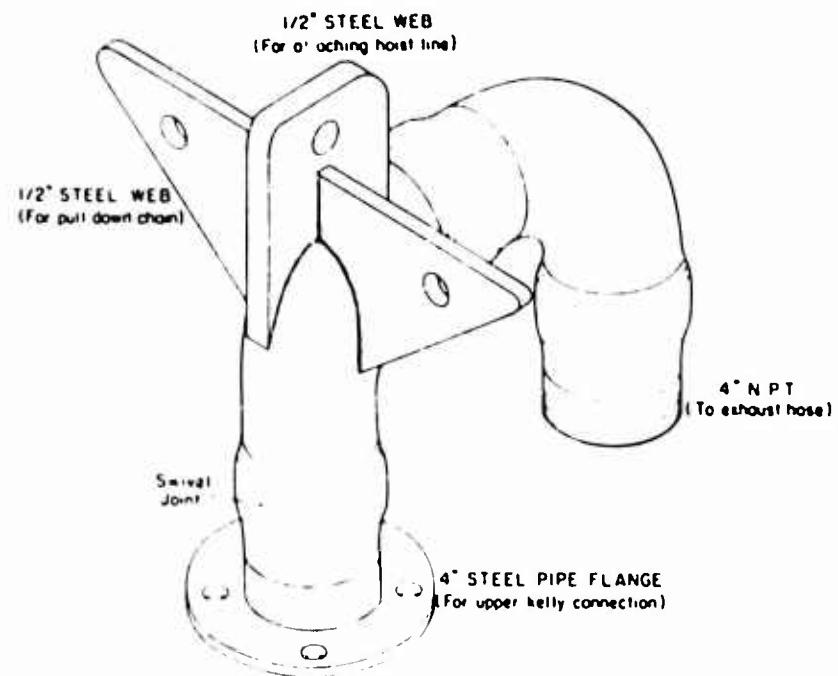


Figure 9. Detail of Chiksan swivel joint with web modifications.

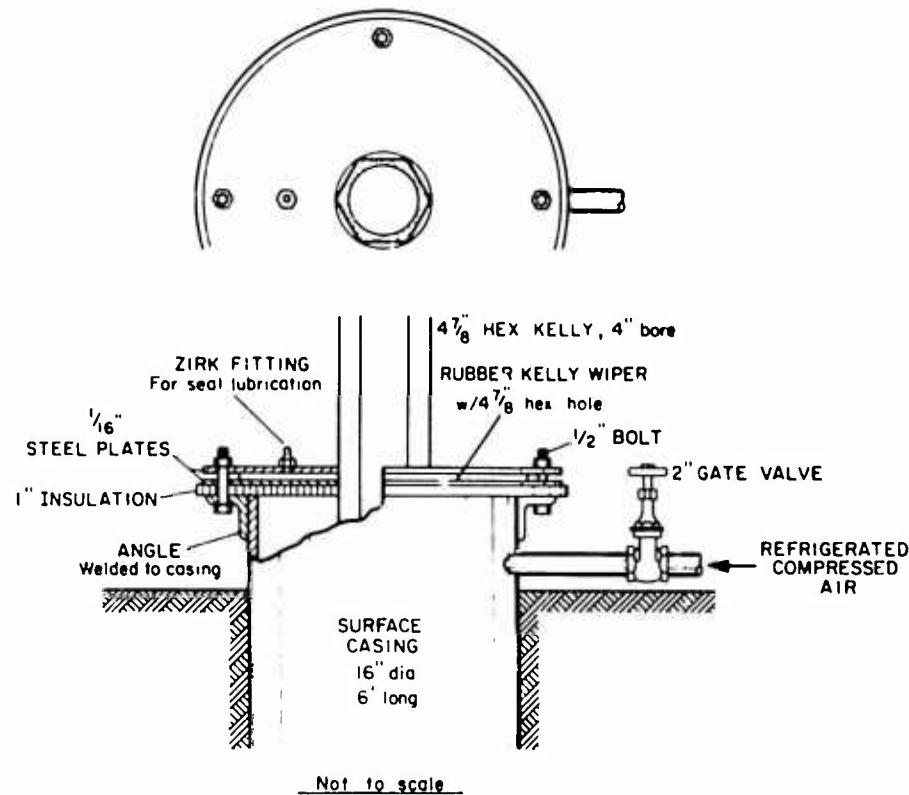


Figure 10. Expedient rotating pressure seal (rubber kelly wiper).

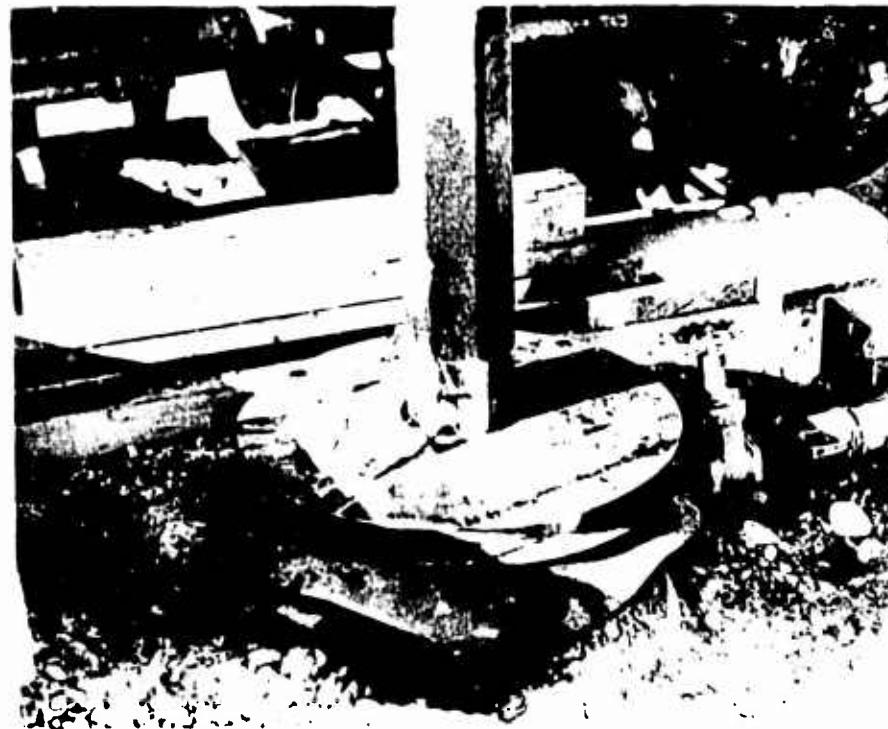


Figure 11. Expedient rotating pressure seal.

An expedient annual seal was fabricated in USA CRREL shops at Fairbanks (Fig. 10, 11) for use with the pressurized annulus system. Modification of the drilling equipment was completed on 5 April.

"BIG HOLE" DRILLING

Augering

There is no way to accurately predict "breakup," that is, the thawing of the active layer in spring. When this occurred, the winter road from the highway to the site would become impassable to wheeled vehicles, especially heavily loaded trucks. Therefore, it was decided to use the Williams Auger (4D-50, capacity: 36-in. hole to 50 ft) to drill the first 50 ft. Accordingly, a 2-ft gravel pad was constructed and on 7 April the truck-mounted auger was taken to the site and 48 ft of 16-in. hole was drilled in about 5 hours using an Alaskaug bit (Fig. 12, 13).

At a depth of 48 ft an explosion occurred in the hole. There were no injuries or damage, but a sheet of orange flame several feet high came from the hole collar and the crew heard and felt the blast. The exact cause of this is not certain. Gas (probably methane) from decaying organic material may have accumulated in the semipermeable frozen gravel and been ignited by sparks from the auger bit, as has previously happened in the Fairbanks District. Before drilling began the following morning, a lighted rag was dropped down the hole but apparently no additional gas had accumulated.

Rotary drilling

The modified Failing 1500 was moved on the hole 11 April to deepen it to 85 or 90 ft (Fig. 14). Initially two 600-ft³/min compressors were used to drive the 4-in. eductor (Fig. 15). The Grant

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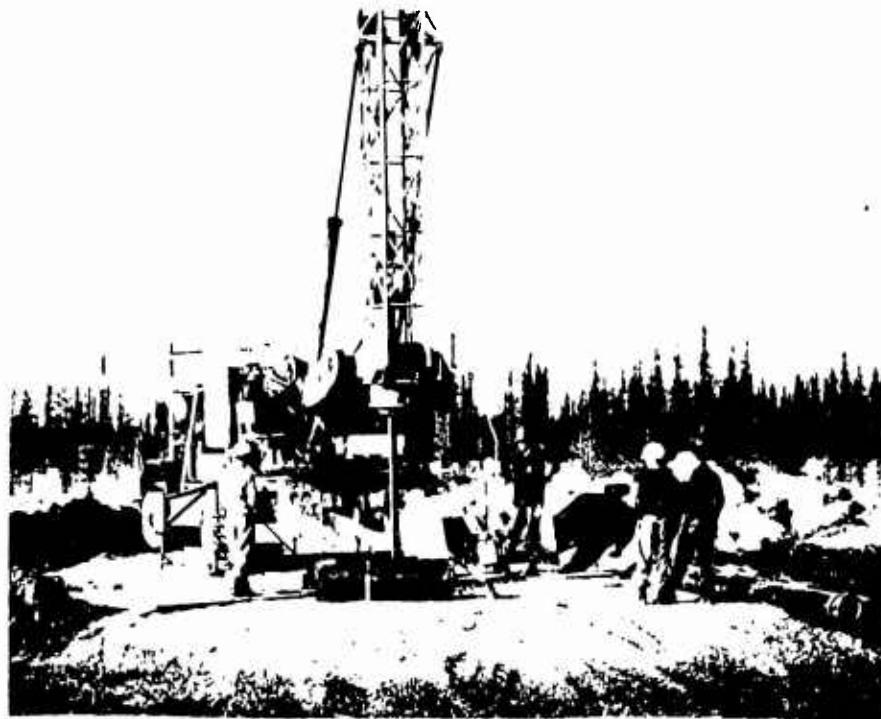


Figure 12. Williams Auger.

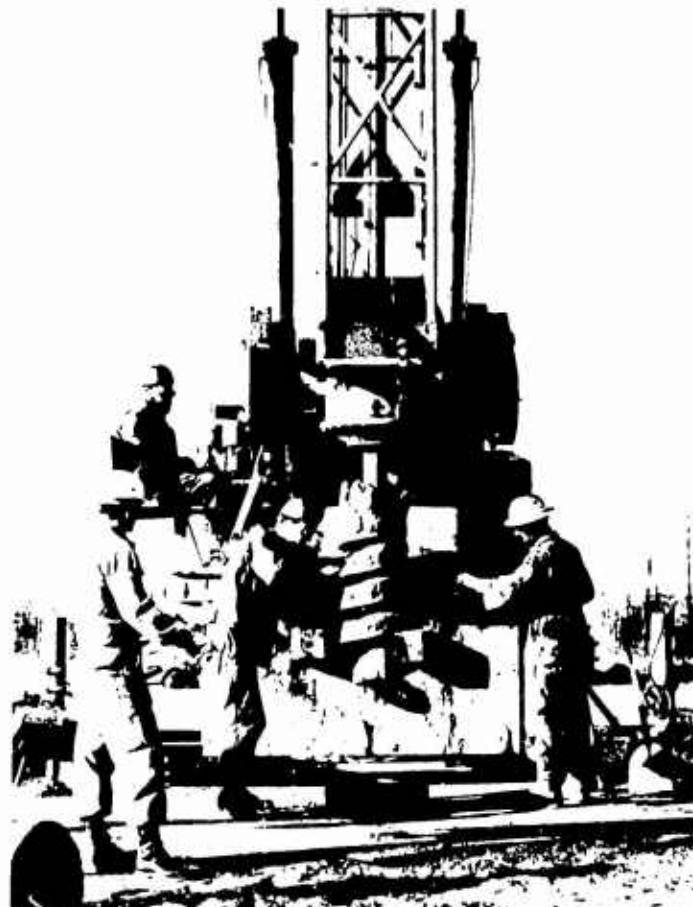


Figure 13. Close-up of Williams Auger.



Figure 14. Moving Failing 1500 over winter access road.



Figure 15. 4-inch air eductor.



Figure 16. 15-inch Grant Simplex bit; note beginning of build up of frozen silt particles on teeth.

Simplex 15-in. bit (Fig. 16) and a 14-in. Alaskaug (modified for reverse circulation) were used in the first attempts. Progress was very slow due to frequent halts to clean the drill pipe and bits.

Clogging occurred chiefly when the cuttings were finer grained, i.e. of frozen silt (Fig. 16), and appeared to be less of a problem when the cuttings consisted of frozen sand and gravel. Also, clogging appeared to be a function of temperature. As the temperature of the ambient air entering the hole annulus (and eventually flowing up the pipe carrying the cuttings) rose to near the freezing point, clogging occurred more rapidly and frequently. Similar effects have been observed when conveying snow pneumatically and when drilling in frozen silt with chilled compressed air in the normal direction of circulation. No simple explanation is offered for this curious and irritating phenomenon. It would seem unreasonable that cuttings of frozen fine-grained soil, or snow for that matter, should agglomerate or clog at pipe bends, etc. when the entire system (cuttings, air and pipe) appears to be at temperatures below freezing. This does not occur when the transporting fluid is liquid.

Slightly better results were achieved with bits provided with shrouds to distribute air flow over the entire hole bottom, such as the Smith rock bits. Also, it was felt that if larger cuttings could be produced, clogging might be minimized. For these reasons a finger drag type bit with air ducting shrouds was fabricated in the Alaska Field Station shop (Fig. 17). However, clogging occurred when using this bit as well.

Until this time, 17 April, air had been circulated solely by the air eductor. This meant that ambient air was drawn into the open hole annulus and used to drive the cuttings from the bit up the pipe and kelly, around the swivel and out the exhaust hose. The weather at the time was warm (Table 1). It is also likely that although the air temperature measured in a shaded instrument shelter was below freezing, the kelly and swivel received enough solar radiation to raise the temperature of their inside surfaces to above freezing, thereby causing cuttings to melt and agglomerate. For these



Figure 17. Field fabricated fingertype drag bit with shrouds.

reasons the compressed air refrigeration equipment, which consisted of a 5-ton Freon compressor driving a brine (glycol) to drilling fluid chiller (Fig. 18) was mobilized and an expedient rotating pressure seal was fabricated, in preparation for drilling with the pressurized annulus scheme. Details of the field-fabricated seal are shown in Figures 10 and 11.

In spite of the care taken in preparing it for this operation, the refrigeration equipment was damaged during the drilling. Also, the weather was warming rapidly (note warming trend starting on 15 April, Table I). The combination of warm ambient air temperatures and refrigerator damage prevented the delivery of air cooler than about 26°F to the annulus and the resulting difficulties reported above prevented appreciable progress. Also at this time the access road began to show signs of thaw.

The expedient rotating pressure seal worked well. The pressure loss in the entire system was about 5 to 6 psi at 80 ft, which was approximately the calculated design value. The seal contained this pressure satisfactorily; further, as soon as clogging started in the bit ports, the seal leaked and this leakage, being easily detected, quickly called attention to incipient bit plugging that would otherwise have gone unnoticed.

After sunset at about 2000 hours on 19 April, the ambient air temperature dropped rapidly to about 15°F. Using the Smith 13 $\frac{3}{4}$ -in. shrouded rock bit, the hole was advanced from 77 ft to 92 ft in less than 1 $\frac{1}{2}$ hours. Short-time drilling rates of over 10 ft/hr were recorded, no bit plugging or clogging of the pipe was noted as the bit penetrated frozen gravel, sand and silt. Up to this point two compressors (a total of 1200 ft³/min) had been used; however, once it was clear that the hole could now be completed to a satisfactory depth, one compressor was shut down and 600 ft³/min was found sufficient to carry 2- to 3-in. gravel particles up the 4-in. pipe. This also verified design calculations.

18 CONSTRUCTION OF AN UNATTENDED SEISMOLOGICAL OBSERVATORY IN PERMAFROST

Table I. Summary of weather during USO construction, Alaska Field Station.

Date March 1966	Max temp (°F)	Min temp (°F)	Avg temp (°F)	Avg wind vel (mph)	Date April 1966	Max temp (°F)	Min temp (°F)	Avg temp (°F)	Avg wind vel (mph)	Date May 1966	Max temp (°F)	Min temp (°F)	Avg temp (°F)	Avg wind vel (mph)
1	12	11	11	11	1	1	38	10	24	1	56	25	40	4
2	13	12	12	12	2	2	49	10	30	2	54	25	40	2
3	15	13	13	13	3	3	48	14	31	2	55	27	41	3
4	16	14	14	14	4	4	39	24	32	3	53	36	40	3
5	17	15	15	15	5	5	35	9	22	1	5	25	40	2
6	16	14	14	14	6	6	43	2	22	1	6	63	32	48
7	13	11	13	13	7	7	39	9	24	1	7	59	32	46
8	20	16	16	16	8	8	37	6	22	3	8	47	38	42
9	18	15	18	18	9	9	39	0	20	2	9	55	27	41
10	21	18	21	21	10	10	44	5	26	2	10	51	26	38
11	22	19	22	22	11	11	29	17	23	2	11	47	27	37
12	21	19	21	21	12	12	34	2	18	2	12	44	18	31
13	22	19	22	22	13	13	30	-5	12	2	13	54	35	44
14	23	20	23	23	14	14	27	-6	10	0	14	49	32	40
15	24	21	24	24	15	15	32	-5	11	0	15	38	30	34
16	23	20	23	23	16	16	48	2	25	1	16	40	24	32
17	24	21	24	24	17	17	53	18	30	1	17	54	24	39
18	25	22	25	25	18	18	39	62	36	1	18	47	31	39
19	26	23	26	26	19	19	35	10	22	3	19	50	28	38
20	27	24	27	27	20	20	31	2	16	4	20	52	25	40
21	26	23	26	26	21	21	22	-10	6	2	21	56	25	40
22	27	24	27	27	22	22	27	-7	10	2	22	57	40	48
23	28	25	28	28	23	23	31	-4	14	2	23	55	32	44
24	27	24	27	27	24	24	37	-3	17	2	24	57	29	43
25	26	23	26	26	25	25	35	3	19	3	25	48	32	40
26	25	22	25	25	26	26	44	18	31	3	26	51	29	40
27	24	21	24	24	27	27	47	18	32	1	27	58	28	43
28	23	20	23	23	28	28	54	21	38	1	28	55	29	42
29	22	19	22	22	29	29	54	29	42	2	29	60	30	45
30	21	18	21	21	30	30	55	25	40	3	30	53	37	45
31	21	18	21	21	31	31	51	29	40	31	61	40	50	3
32	21	18	21	21	31	31	52	29	40	31	61	40	50	3
33	21	18	21	21	31	31	52	29	40	31	61	40	50	3
34	21	18	21	21	31	31	52	29	40	31	61	40	50	3
35	21	18	21	21	31	31	52	29	40	31	61	40	50	3
36	21	18	21	21	31	31	52	29	40	31	61	40	50	3
37	21	18	21	21	31	31	52	29	40	31	61	40	50	3
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39	21	18	21	21	31	31	52	29	40	31	61	40	50	3
40	21	18	21	21	31	31	52	29	40	31	61	40	50	3
41	21	18	21	21	31	31	52	29	40	31	61	40	50	3
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43	21	18	21	21	31	31	52	29	40	31	61	40	50	3
44	21	18	21	21	31	31	52	29	40	31	61	40	50	3
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46	21	18	21	21	31	31	52	29	40	31	61	40	50	3
47	21	18	21	21	31	31	52	29	40	31	61	40	50	3
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49	21	18	21	21	31	31	52	29	40	31	61	40	50	3
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51	21	18	21	21	31	31	52	29	40	31	61	40	50	3
52	21	18	21	21	31	31	52	29	40	31	61	40	50	3
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56	21	18	21	21	31	31	52	29	40	31	61	40	50	3
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75	21	18	21	21	31	31	52	29	40	31	61	40	50	3
76	21	18	21	21	31	31	52	29	40	31	61	40	50	3
77	21	18	21	21	31	31	52	29	40	31	61	40	50	3
78	21	18	21	21	31	31	52	29	40	31	61	40	50	3
79	21	18	21	21	31	31	52	29	40	31	61	40	50	3
80	21	18	21	21	31	31	52	29	40	31	61	40	50	3
81	21	18	21	21	31	31	52	29	40	31	61	40	50	3
82	21	18	21	21	31	31	52	29	40	31	61	40	50	3
83	21	18	21	21	31	31	52	29	40	31	61	40	50	3
84	21	18	21	21	31	31	52	29	40	31	61	40	50	3
85	21	18	21	21	31	31	52	29	40	31	61	40	50	3
86	21	18	21	21	31	31	52	29	40	31	61	40	50	3
87	21	18	21	21	31	31	52	29	40	31	61	40		



Figure 18. Compressed air refrigeration equipment.

DISCUSSION OF "BIG HOLE" DRILLING

While very little "big hole" footage (44 ft) was drilled with the lightweight reverse circulation rotary equipment, the initial difficulties encountered and the final success gave information that will be of value if installation of USO's in permafrost is seriously considered again, or if any drilling project is attempted in permafrost where "big holes" with little rigs are required.

Eductor vs pressurized annulus

The eductor scheme is convenient because the annulus of the hole is open at the top and there is no need to install and remove the pressure seal each time a joint of pipe is added and whenever the string is removed from the hole. Bolts were used to clamp the seal to the top of the surface casing, but quick acting clamps could have been used to eliminate this inconvenience. Since the eductor system requires that ambient air be drawn down the hole, there is no way to control the temperature of the air circulating in the drill string. It seems clear that drilling with this system cannot be accomplished at ambient air temperatures above, say, 20 F. Further, the system requires a great deal more compressed air than the pressurized annulus - at least 1200 ft³ min at 100 psig for the 4-in.-ID drill string and the 4-in. eductor.

The pressurized annulus scheme has a number of advantages. First, it requires only 600 ft³ min of air at no more than about 15 or 20 psig for 200-ft drphs with 4-in.-ID drill pipe. This could be quite easily accomplished with low pressure, high volume positive displacement compressors, less than the 110 psig standard construction type compressors. Air temperature in the annulus can be controlled (with properly functioning refrigeration equipment) at any rate desired. Drilling could be accomplished in summer weather with a 50°F air temperature in the hole. However, the hole would have to be shielded from solar radiation - a quite difficult task. In winter, however, drilling would be feasible.



Figure 19. Air impact wrench making up bolts on 4-in. flanged drill pipe.

Rig, bits and other equipment

The modified rig served well as an expedient to drill the one hole required and would have been adequate for the additional drilling trials that were proposed by USA CRREL. After only limited experience with this particular drilling problem, a reverse circulation compressed air system would be recommended. A more suitable rig could probably be obtained or fabricated from easily available components but it is beyond the scope of this report to develop the design criteria for such a rig.

Bits designed for reverse circulation of water, such as the Alaskaug reverse circulation water well bit, are not suitable for use with reversed circulation of compressed air because the air flow is not directed over the entire hole bottom for proper bottom hole cleaning. The Grant Simplex bit (Fig. 16) appears to have fair ducting characteristics but was not used under the favorable air temperature conditions required for proper evaluation. The shrouded (ducted) Smith rock bit was the only bit used during the last 15 ft of drilling, when acceptable rates of penetration were maintained. It appeared to be correctly designed for reverse circulation of compressed air. Bottom hole cleaning has been a problem in the recent rapid development of "truly big holes" (4- to 10-ft. diam) and some novel bottom hole cleaning systems have been devised which might be applicable to our "little rig, big hole" problem.*

The 4-in. bolt-flanged coupled pipe worked well and was more convenient to make and unmake than was expected, partly because of the use of an air-driven impact wrench (Fig. 19). Threaded drill pipe and power tongs should be reconsidered for future development. Threaded drill pipe up to 12 in. ID is in common use in the "truly big hole" industry.* The substitution of the Chiksan joint for the rotary swivel was also satisfactory but a longer radius bend would have eliminated some clogging of the drill string.

*Samuelson, W.V., et al. (1966) Construction techniques and costs for underground emplacement of nuclear explosives. U.S. Army Engineer District, Fort Worth, Texas, for U.S. Atomic Energy Commission.



Figure 20. Setting casing.

CASING

The 11½-in. ID \times 11½-OD step-threaded flush joint casing was set on 21 April (Fig. 20). Before the blind bottom casing was lowered into the hole, 15 ft³ of a well-mixed slurry consisting of silt, water and snow was poured into the hole. The temperature of the slurry was close to 32° F and it had a total water content (water and snow) of 75% (weight water/weight dry soil). After the slurry was poured the casing was forced, by its own weight, into the hole. The casing forced the slurry into all available space and minimized the formation of voids in the narrow (1-in.) annulus between the casing and the hole wall. Fifteen cubic feet of slurry was calculated to be enough to fill the lower 44 ft of 13½-in. hole. Although the weight of the casing exceeded its buoyant force, some of the weight of the rig was placed on it overnight.

The following day, 32 ft³ of slurry consisting of sand, ¼-in. gravel, water and snow was poured in around the casing. About 80 lb of dry ice was dropped to the bottom of the casing to hasten freeze-back. The coarser upper backfill settled into the silt slurry below and displaced some of the silt to the surface before the backfill froze. The total water content of the upper backfill was 15% and the volume of total water (water and snow) in the backfill was about 20 ft³. The casing did not move appreciably after it was set and the backfill was probably frozen in a day or two. Later a check of the plumbness showed the casing to be about 0.2° from plumb. A total of 102.85 ft of casing was set, five joints of 18 ft each plus one short joint. The casing was initially cut off (22 April) at a total length of 94 ft. It was again cut shorter after the surface instrument shelter was installed over it.

The step-threaded joints worked very well (Fig. 21) and in spite of the higher cost are much to be preferred over field welding for many applications.



Figure 21. Making up casing joints.

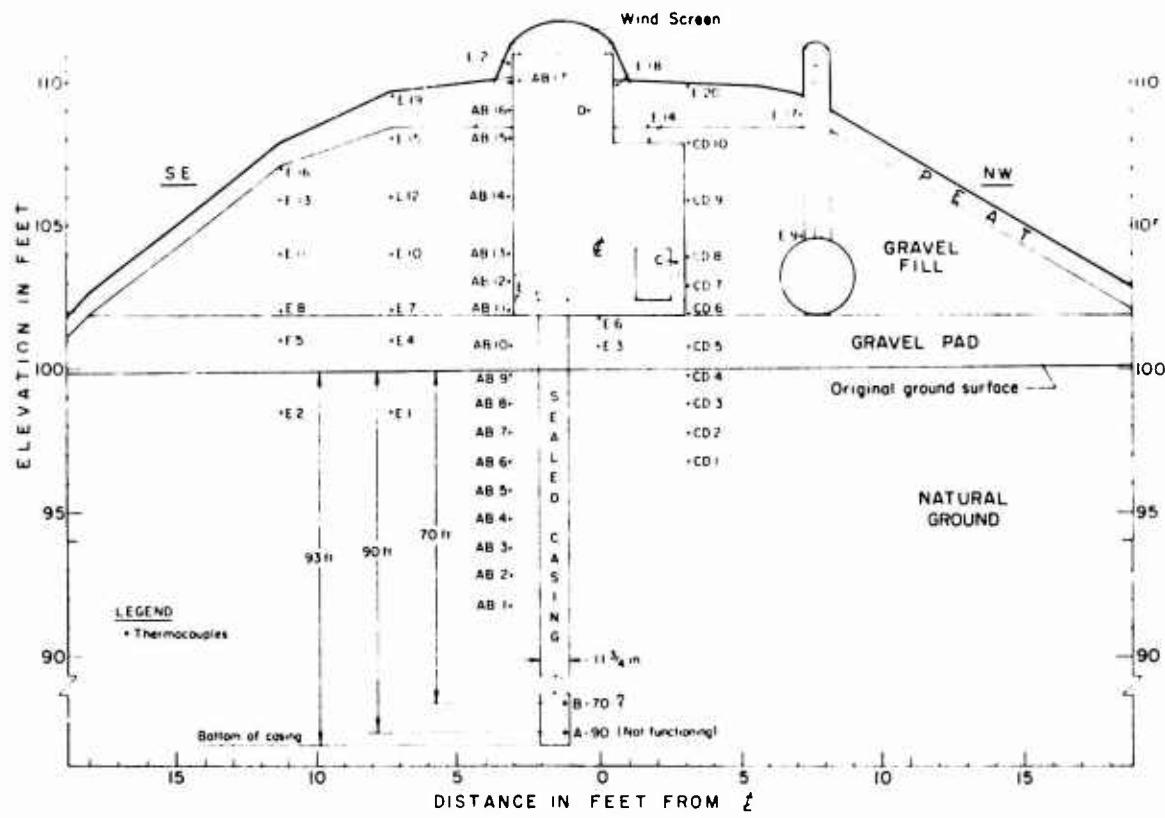


Figure 22. Thermocouple locations, June 1966.

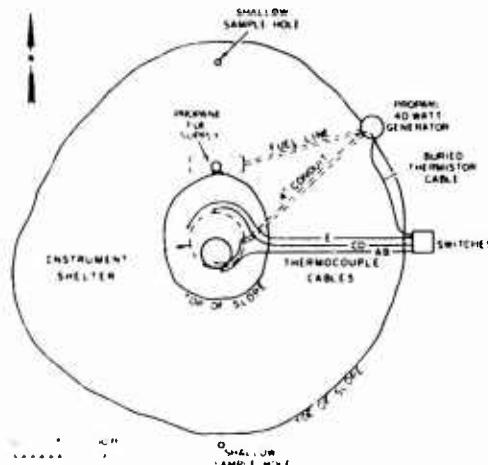


Figure 23. Thermocouple cable layout and shallow sample hole location, June 1966 (plan view).

was omitted but this is not considered important. Additional thermocouples were taped to the outside of the instrument shelter (Fig. 24). The gravel fill, which had been stockpiled at the site, was then placed around the surface shelter with a D-8 bulldozer. Fair compaction was achieved, at least in the lower lifts, by the tractor tracks. Because of the steep slopes, the upper lifts had to be placed by hand. It is estimated that the design values for fill density (105-125 lb/ft³) and moisture content (2-3%) were achieved. At this point it appeared that the fill was a little short of the design volume, this was confirmed by cross-sectioning. By scraping up spilled gravel around the site and using peat judiciously, most of this deficiency was compensated. The results of final cross-sectioning (Fig. 22) show close correspondence to the design volume and shape. It was impossible to haul more fill because of the load restrictions temporarily in force to protect the highway pavements during the spring thaw. The "as built" positions of the propane tank, thermoelectric generator, and connecting conduit are also shown in Figures 22 and 23.

The borehole seismometer package was placed in the hole and locked 2 ft from the bottom of the casing on 26 April. The Williams Auger was used to transfer the package from the truck trailer to the top of the borehole (Fig. 25). Before the package was lowered into the hole, five USA CRREL thermistor probes were taped to the outside of the unit (Fig. 26, 27). Three thermocouples were placed in the surface instrument shelter to monitor the air temperature (Fig. 28). Leads for these thermocouples and the borehole package thermistors were carried out of the instrument shelter through the 4-in. conduit (which also contains the power cable from the generator to the recorder module) to the thermoelectric generator and then were buried in the surface fill at the toe of the slope, between the generator and the switch box (Fig. 23). Peat was spread over the mound so that the surface could be seeded. This was accomplished by 1 May and the shelter was locked on 3 May (Fig. 29).

SURFACE CONSTRUCTION

The bore hole seismometer package arrived by C-47 on 21 April. The drill rig was moved off the hole on the 22nd and the thermocouples were placed in the shallow holes and in the fill. The final location of all thermocouples and the cable layout are shown in Figures 22 and 23.

Surface fill and instrument shelter

The instrument shelter was placed on the gravel pad and leveled on 23 April. Care was taken in final finish of the surface fill in order to furnish a model which closely resembled that used in the engineering study, in order to validate predictions of heat flux through the fill and resulting shelter temperatures which approached critical values for recorder performance.

The sand leveling course which was originally specified

was omitted but this is not considered important. Additional thermocouples were taped to the outside of the instrument shelter (Fig. 24). The gravel fill, which had been stockpiled at the site, was then placed around the surface shelter with a D-8 bulldozer. Fair compaction was achieved, at least in the lower lifts, by the tractor tracks. Because of the steep slopes, the upper lifts had to be placed by hand. It is estimated that the design values for fill density (105-125 lb/ft³) and moisture content (2-3%) were achieved. At this point it appeared that the fill was a little short of the design volume, this was confirmed by cross-sectioning. By scraping up spilled gravel around the site and using peat judiciously, most of this deficiency was compensated. The results of final cross-sectioning (Fig. 22) show close correspondence to the design volume and shape. It was impossible to haul more fill because of the load restrictions temporarily in force to protect the highway pavements during the spring thaw. The "as built" positions of the propane tank, thermoelectric generator, and connecting conduit are also shown in Figures 22 and 23.

FLOODING

On 5 May the water began to rise at the site and the entire Chena drainage basin began to flood. Since local flood control officials predicted that a crest several feet higher than prevailing water levels was due in a couple of weeks it was decided to provide some protection for the installation.

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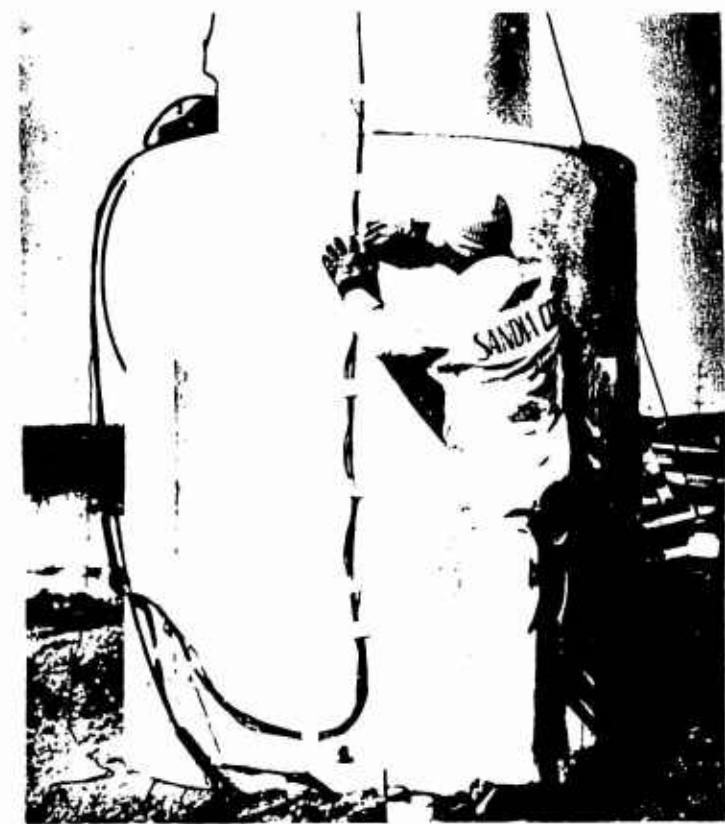


Figure 24. Taping thermocouples to outside of instrument shelter.



Figure 25. Installing borehole package with Williams Auger.



Figure 26. USA CRREL thermistors on borehole package.

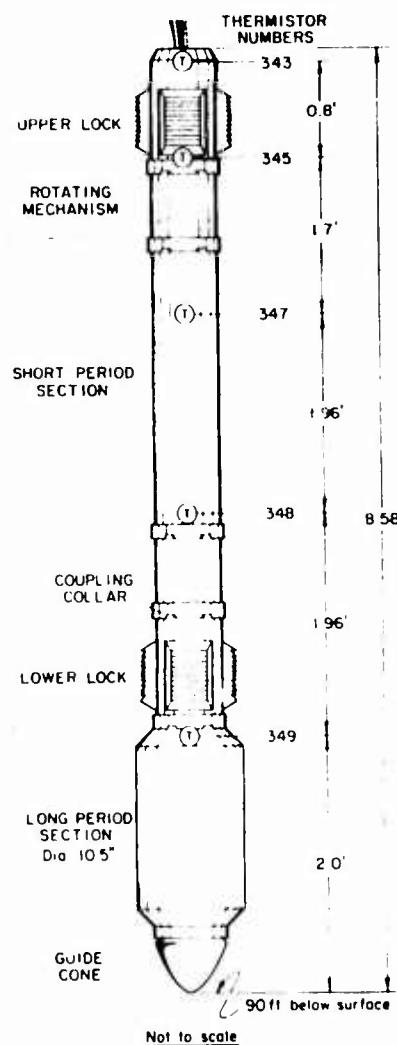


Figure 27. Location of CRREL thermistors (T) on USO borehole package.

With the assistance of the Resident Engineer and a troop unit from Fort Wainwright, a sandbag dike which afforded about 2 ft of freeboard, backed by a polyethylene sheet, was constructed during the night of 6-7 May (Fig. 30). Apparently the flood crested that same night. An aerial inspection (Fig. 31, 32) revealed that several beaver dams were interfering with the drainage at the site. The dams were partially destroyed with hand tools, effecting a noticeable drop in water level.

TERMINAL ACTIVITIES

The Sandia team revisited the site on 17 May and an ARPA representative inspected the site on the 18th. Grass seed was sown on the peat cover on 31 May.

The area around the base of the fill and the undisturbed ground nearby was probed for the depth of thaw in mid-August and it appeared that the construction activity had caused no substantial depression of the permafrost table.

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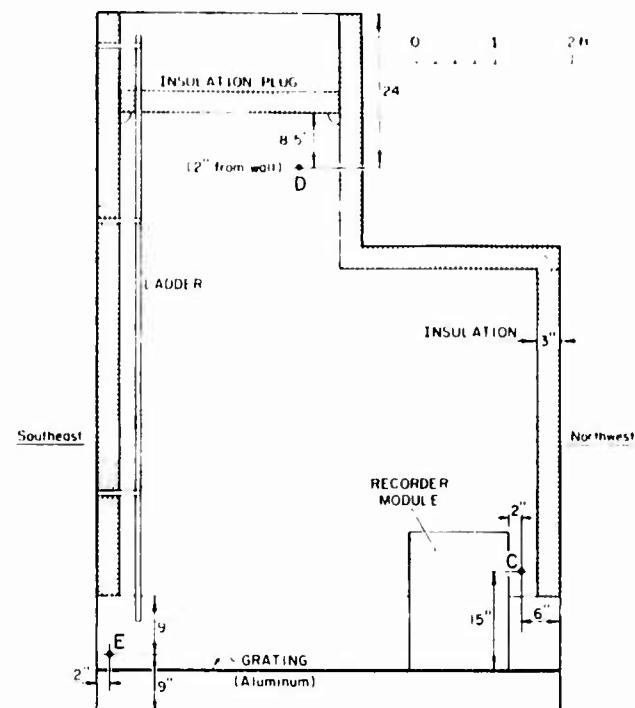


Figure 28. Northwest-southeast section of USO shelter showing interior thermocouple (C, D, & E) locations.



Figure 29. Installation complete.



Figure 30. Installation several days after flood crest showing sand bag dike and plastic sheet.

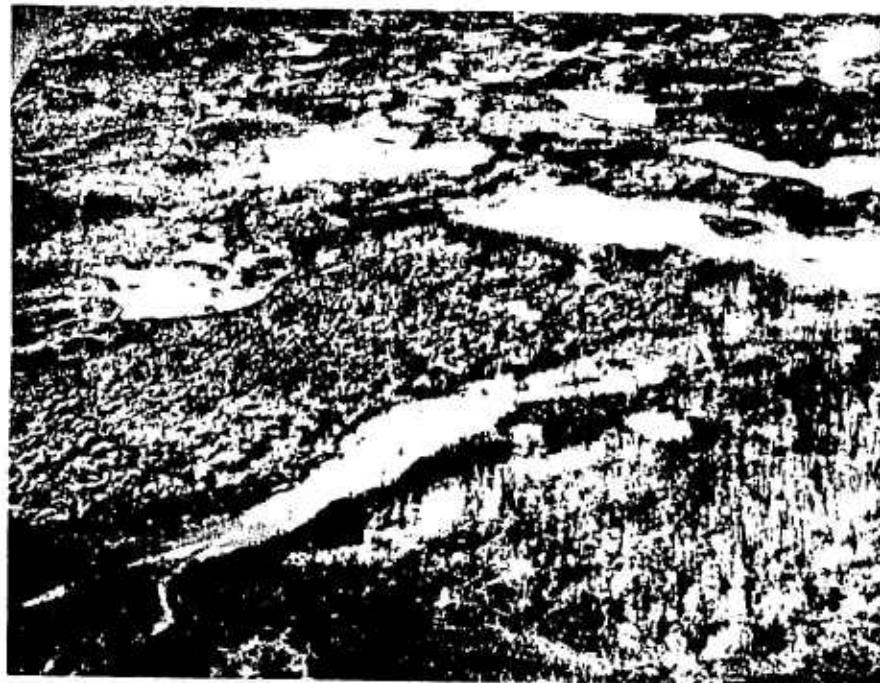


Figure 31. Aerial view of site (lower left) several days after flood crest, looking S.W.

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Figure 32. Aerial view several days after crest of flood – note flooded access road.



Figure 33. View of site in October 1966.

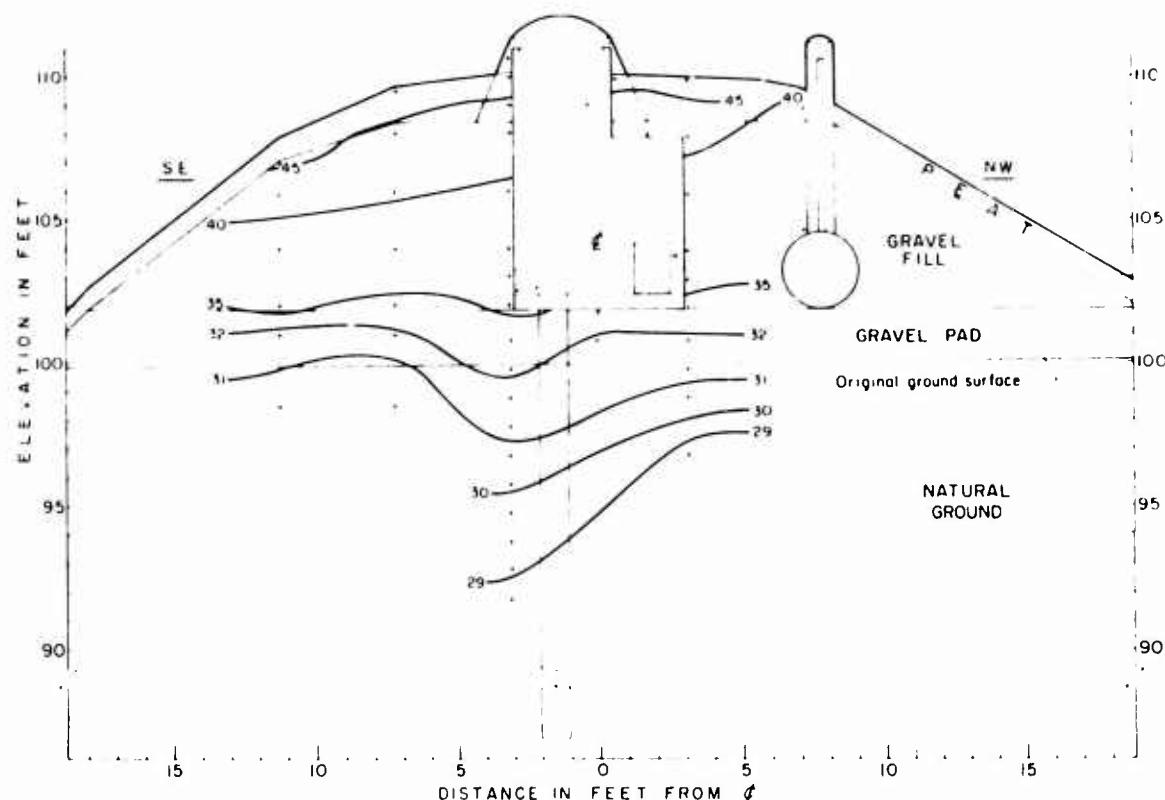


Figure 34. Isothermal profile ($^{\circ}$ F), 31 May 1966. Probes were believed to be in equilibrium with surrounding media by this date.

Figure 33, taken in October 1966, shows an absence of grass and some peat; the seed and some of the dry peat were probably removed by the wind during the unusually dry summer.

THERMAL PERFORMANCE AND SETTLEMENT OF THE FILL

Temperature data

A CRREL Special Report, *The Thermal Performance of an Unattended Seismological Observatory Near Fairbanks, Alaska*, by Richard Berg covers the entire two-year period of seismic and thermal records. Weekly temperature values were obtained with the 40 thermocouples in the fill and in shallow subsurface holes (Fig. 22), 3 thermocouples in the instrument shelter (Fig. 28) and 5 thermistors located on the borehole seismometer package. A continuous record of the outside ambient air temperature was obtained with a thermograph located in a standard meteorological instrument shelter about 100 ft south of the fill. Four isothermal profiles for May-December 1966 are presented in Figures 34-37. Weekly temperatures inside the instrument shelter and average daily outside air temperatures for the same period are shown in Figure 38.

Additional subsurface data

On 8 August 1960 Mr. Paul Sellmann of USA CRREL sampled two holes at the site to depths of 4.9 and 6.1 ft. The location of these holes is shown in Figure 23 and a descriptive log of the materials encountered is presented in Figure 39. Laboratory tests show that volumetric ice contents average 70% in the frozen peat, which extends to a depth of 3.5-4.0 ft (Sellmann, personal communication).

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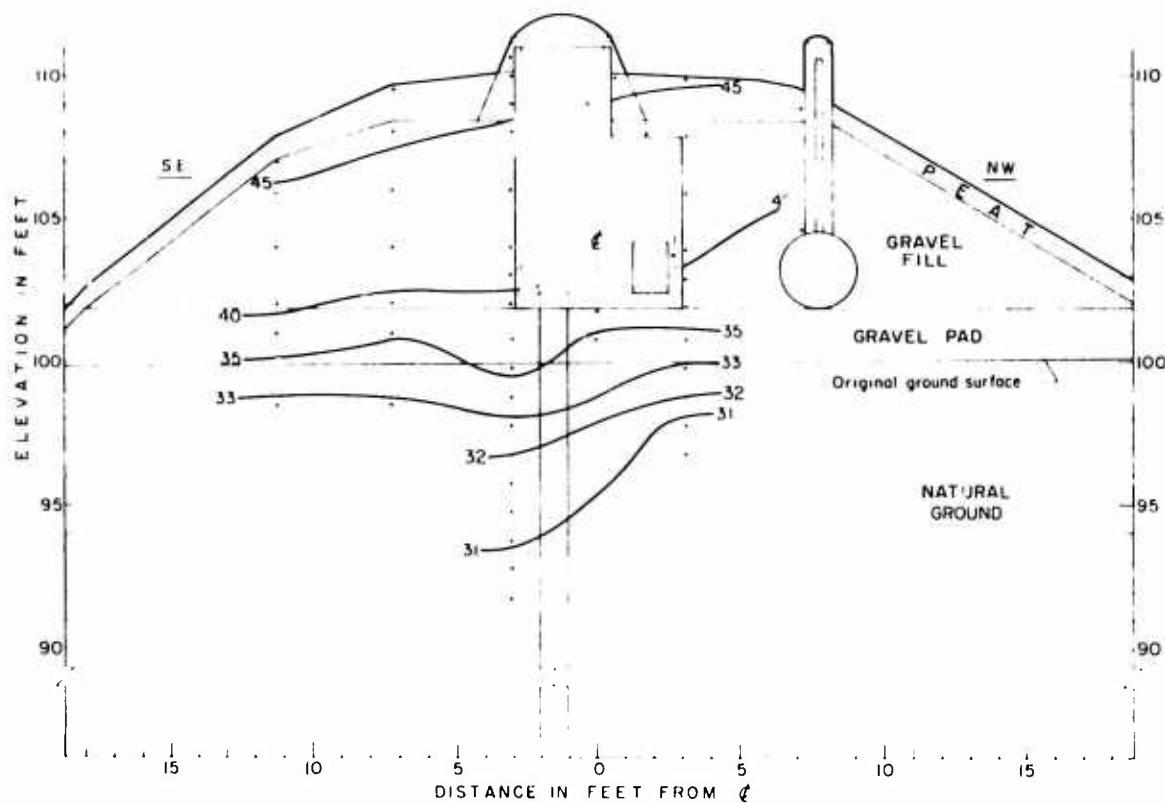


Figure 35. Isothermal profile ($^{\circ}$ F), 13 Sept 1966 (maximum thaw penetration).

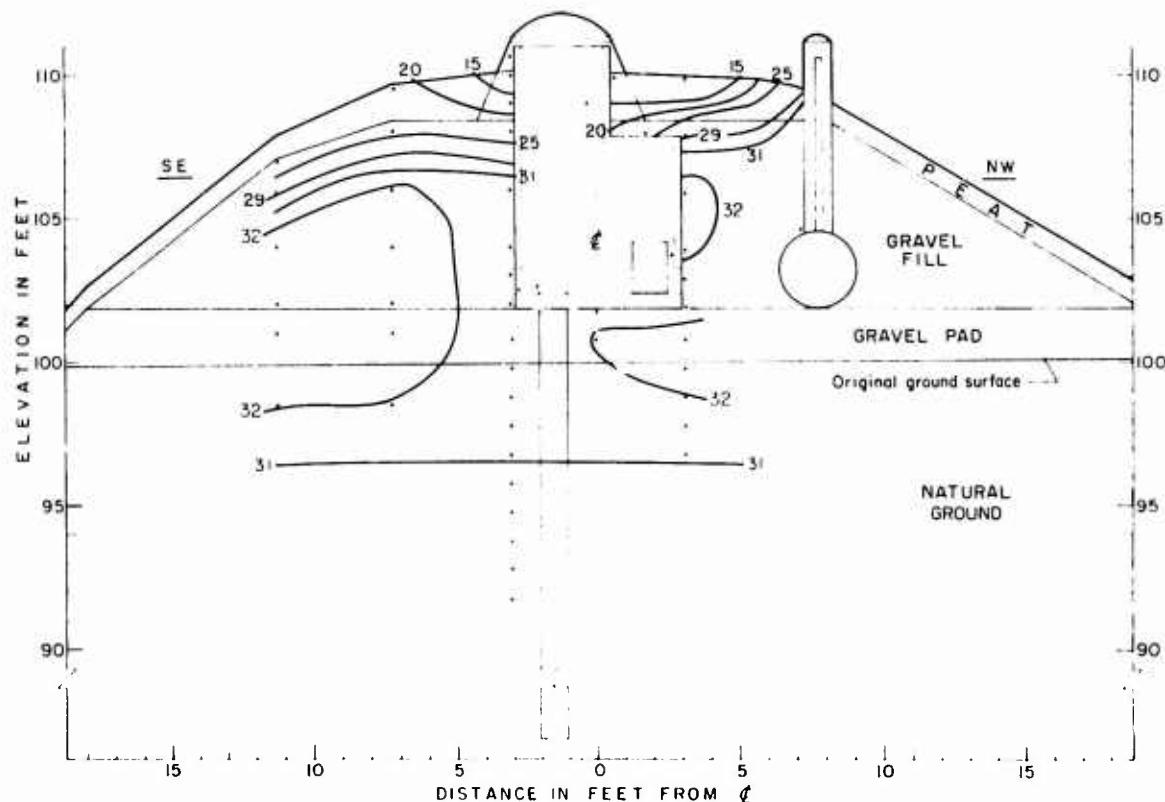


Figure 36. Isothermal profile ($^{\circ}$ F), 28 Oct 1966. Measurements on this date showed 8 in. of settlement.

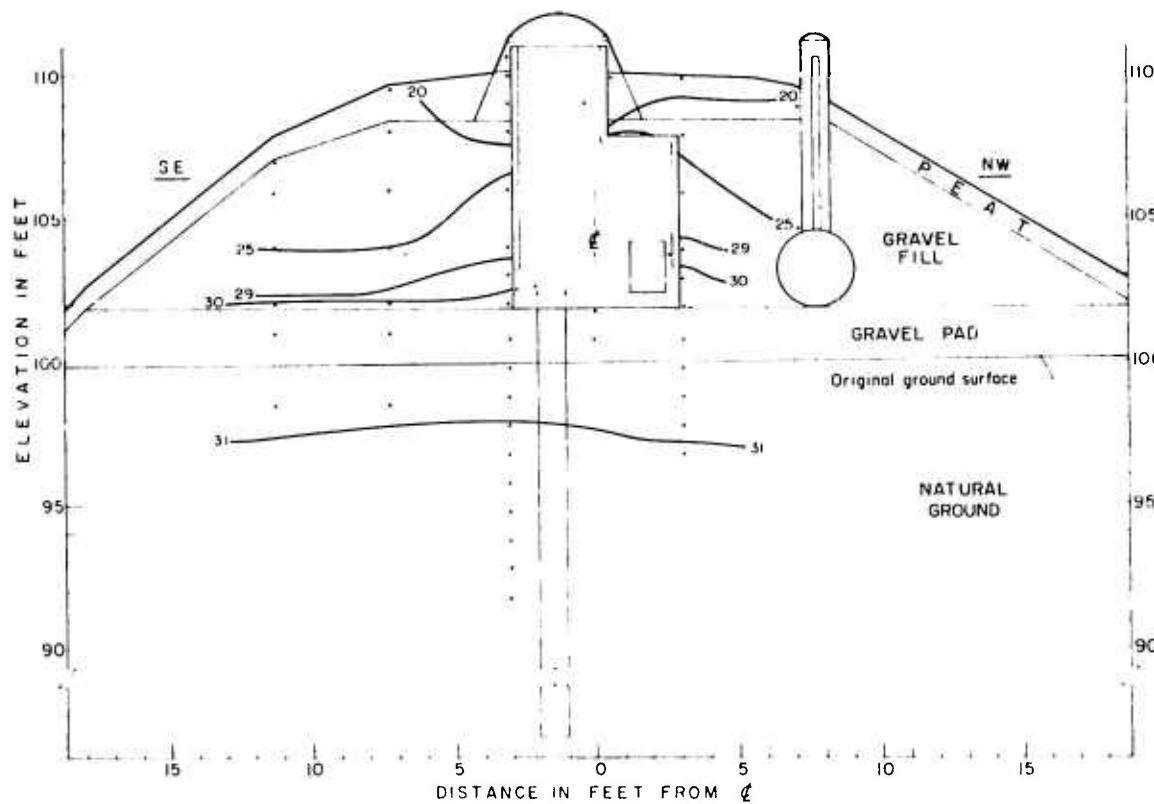


Figure 37. Isothermal profile ($^{\circ}$ F) 1 Dec 1966.

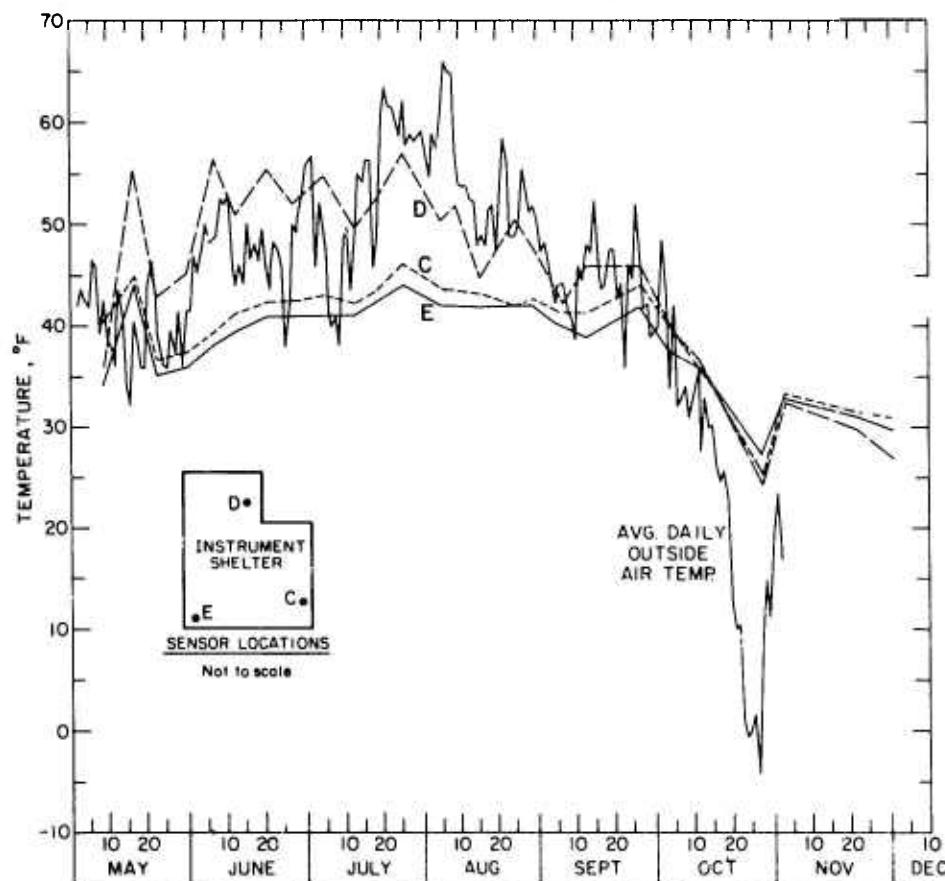


Figure 38. Air temperature inside and outside of instrument shelter at USO site.

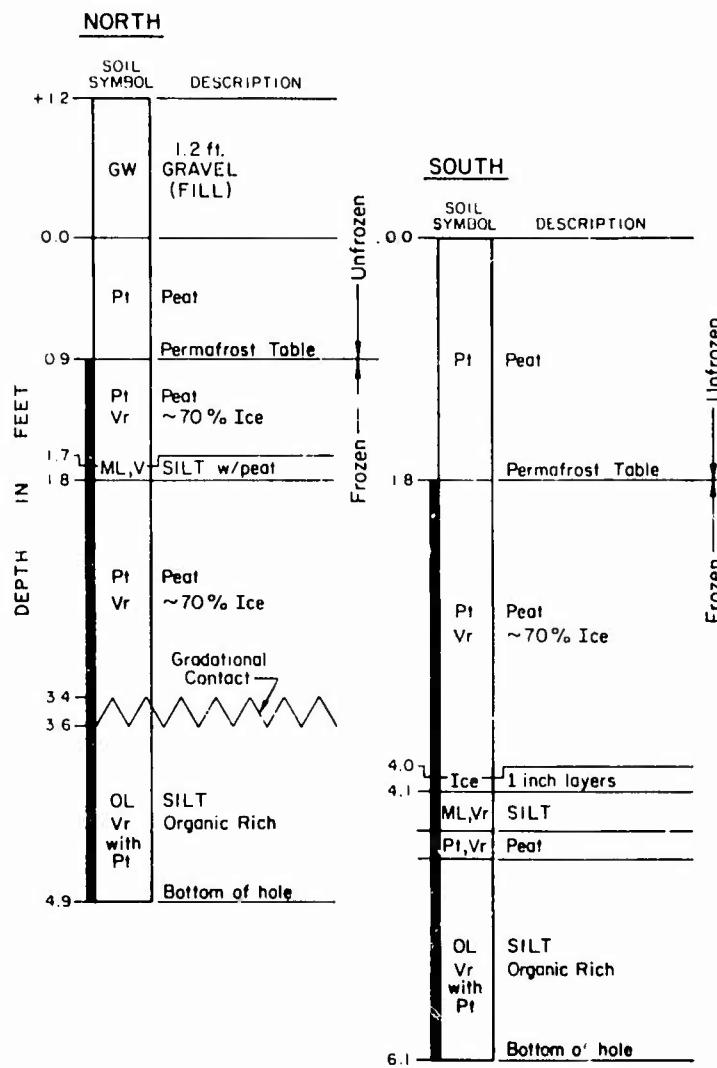


Figure 39. North and south shallow sample holes (data from P.V. Sellmann).

Sandia personnel entered the shelter in late October and measured nearly 8 in. of settlement, i.e. downward movement of the floor of the shelter relative to the top of the 90-ft casing.

Discussion

The maximum depth of thaw (Fig. 35) is about 3 ft. Thus, the settlement amounts to about 25% of the thawed depth. Sellmann (personal communication), using empirical data from load tests on peat in other locations, estimated that the settlement should be between 25% and 35%. While these data appear to be in rough agreement, the isothermal plot of 28 October (Fig. 36) shows that the temperatures at all of the subsurface probes were below freezing. This suggests that most of the settlement had probably taken place by 13 September for the following reasons. Since heaving is caused by the freezing of the soil it only occurs as the soil freezes. Therefore, since all of the probes below the floor of the shelter indicated below-freezing temperatures on 28 October, no further heave or settlement would take place until the next summer. In view of the above considerations, it is quite possible that more than 8 in. of settlement had occurred. Settlement the following summer

would probably be somewhat less than the 8 in. observed and deduced for summer 1966. We do know that surcharge (in our case, 8 ft of gravel or 1000 lb/ft²) inhibits heave, however, our data were all taken from experimentally loaded sections of silt which contained little or no organic material.

THE THERMAL ENVIRONMENT OF THE BOREHOLE PACKAGE AND PERMAFROST TEMPERATURES AT DEPTH

Instruments and data

Five thermistors were taped to the borehole instrument package (Fig. 26, 27). The probes have a response of approximately 300 ohms/°C, and were calibrated at the freezing point of phenol, the triple point of water, and the freezing point of mercury. Calibration tables were generated in a computer using Stanley's program.* A modified Honeywell Model 107±5 portable Wheatstone bridge was used to read the probes in the field by balancing it to the nearest ohm. Bridge accuracy is 0.05% or ± 0.02 ohm by calibration. Self heating was virtually eliminated by reducing the excitation voltage to 0.2 v, causing 20 microwatts dissipation at the probe. The temperatures (Table II) are probably accurate to ± 0.03 °C, with the exception of probe number 349.

Table II. Equilibrium temperatures from thermistor probes on borehole package.

Probe	Depth (ft)	Temp (°C)
343	81.5	0.94
345	82.3	-0.90
347	84	0.88
348	86	0.86
349	88	0.70 ± 0.05 (see text)

Equilibrium temperatures were determined by cursory examination of the data from the field, which showed that after 7 June the resistances of all the probes became stable at a constant value within ± 1.0 ohm, except for number 349 which showed an instability during this time of as much as ± 15 ohms, ± 7 ohms.

Analysis

From the theory of heat conduction in solids, a model of the depth-temperature gradient in permafrost can be constructed. It is shown in Figure 40 along with the temperatures observed on the borehole package. While four equilibrium temperatures along a path of 4.5 ft (neglecting data from probe 349) are indeed sparse data with which to establish temperatures in a permafrost body over 120 ft thick, other data and a general theory are available to reinforce our estimate. If the rocks (or permafrost) do not contain moving groundwater or other fluids, and have a uniform value of thermal diffusivity, and since the geothermal heat flux to the earth's surface at any one location is essentially

*Stanley, L.E. (1965) Calibration equation for type 31 B (1000 ohms at 25 °C, type B material) thermistor probes. U.S. Army Cold Regions Research and Engineering Laboratory (USA-CRREL) (unpublished), Technical Note.

34 CONSTRUCTION OF AN UNATTENDED SEISMOLOGICAL OBSERVATORY IN PERMAFROST

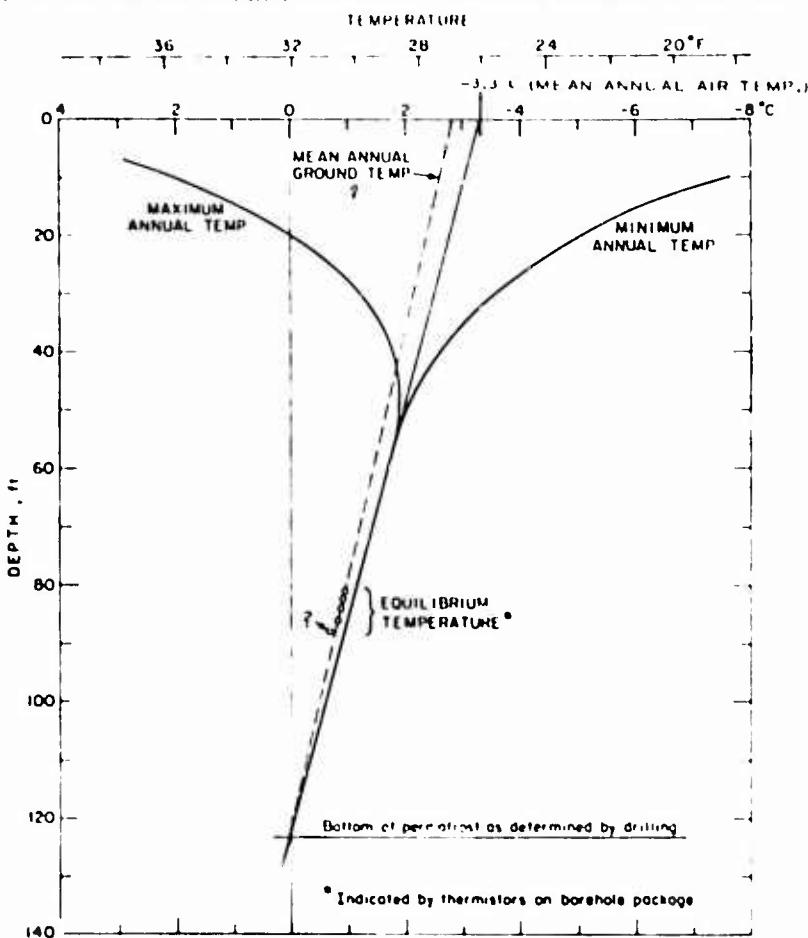


Figure 40. Borehole package temperatures and models of the depth temperature curve.

constant with time, the temperature gradient will be linear.* Data are available that substantiate the assumption that the thermal diffusivity is roughly uniform with depth. Intercepts may be fixed as follows—the mean annual air temperature (-3.3°C for Fairbanks) and 0°C at the bottom of the permafrost. The information gained from the exploratory hole shows that there are no moving fluids in the permafrost at this location and that the bottom of permafrost is at 123 ft. The resulting depth-temperature curve is shown as the straight solid line in Figure 40. Seasonal air temperature fluctuations will effect measurable ground temperature changes down to a depth of about 50 ft.* These temperatures will vary throughout the year within the approximate boundaries marked *minimum annual temp.* and *maximum annual temp.* This is the usual model constructed for a case such as this. The borehole package temperatures are slightly warmer than those predicted by the simple model. This model can be refined by taking the zero depth intercept as the mean annual ground surface temperature at this vegetation-soil interface, rather than using the mean annual air temperature which is obtained from data taken perhaps 4 ft above the ground. The near-surface ground temperature is always slightly warmer than the mean annual air temperature. The dashed line in Figure 40 is the ground temperature curve constructed by connecting the bottom of permafrost with the temperatures from the borehole package and projecting it to the surface. This model fits the data even better. Note that the upper four probes appear to indicate temperatures with the appropriate gradient. Therefore, we can say with reasonable certainty that the borehole package has been in thermal equilibrium

*Lachenbruch, A.H., M.C. Brewe, G.W. Greene and B.V. Marshall (1962) Temperatures in permafrost. In *Temperature, its measurement and control in science and industry*, vol. 3, Part I. New York: Reinhold Publishing Corporation.

with the surrounding permafrost since early June 1966 and can be expected to remain so unless disturbed by the activities of men. These data are of interest because we know of no other measurement of the thermal gradient at an *undisturbed* site in the Fairbanks district.

CONCLUSIONS AND RECOMMENDATIONS

Because of the change in emphasis during the project, it was impossible to fulfill the original objectives. However, we can comment briefly in regard to both the original objective (demonstrating the feasibility of remote arctic construction) and the later objective (constructing the specific installation near Fairbanks).

Construction of a USO in marginal permafrost is possible; construction in colder, continuous permafrost would be easier. Construction in one week's time, although not impossible, would be difficult, even if equipment and techniques were greatly refined.

"Big holes with little rigs" at acceptable rates of penetration are possible in almost any earth material including rock and permafrozen soils but considerable development would be required to assure reasonable success in a wide variety of subsurface conditions with each hole that was attempted.

The gravel till appears to be thermally adequate to protect the instrumentation from temperature extremes and to prevent deleterious thawing of the underlying permafrost. However, the difficulty of obtaining and hauling gravel in a remote arctic environment and the weight and size of the equipment required to handle the gravel strongly suggest that some substitute is needed.

At least 8 in. of settlement occurred due to the thawing of 3 ft of underlying peat of high volumetric ice content. This depth of thaw was expected, however, the high ice content was not. While a maximum of 6 in. of settlement was specified, the more than 8-in. settlement appears to have caused no detrimental effects. The high ice content of the peat was overlooked due to the expedient nature of the exploratory drilling. This emphasizes the need for careful core drilling prior to siting and construction of any critical or expensive structure in any geologic setting.

Construction should be carried out in winter, when the active layer is frozen and the ambient air is at least below 20° F.

The logistic and mobility aspects of remote arctic construction would be formidable. All facilities and equipment required (enclosed, heated and lighted drill rigs, shops, living and messing facilities, etc.) should be mounted on tracked vehicles or tracked trailers towed by tracked prime movers, allowing construction to proceed regardless of environmental extremes.

Before a commitment is made to construct USO's in remote arctic regions, a full scale practice exercise should be implemented at a remote site in northern North America.